Analysis of Hand Held Power Tools for Reducing the Vibration and Force in the Human Hand Arm System

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Industrial Design

By

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CERTIFICATE

This is to certify that the work in the thesis entitled, "**Analysis of Hand Held Power Tools for Reducing the Vibration and Force in the Human Hand Arm System"** submitted by **Mr. Swapnil Shrivastava** in partial fulfilment of the requirements for the award of **Master of Technology Degree** in the Department of Industrial Design, National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the work reported in this thesis is original and has not been submitted to any other Institution or University for the award of any degree or diploma.

He bears a good moral character to the best of my knowledge and belief.

Place: NIT Rourkela

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ABSTRACT

The main objective of this analysis is to find out the effect of hand held power tools on hand arm and reducing the effects of these hand held power tools on hand arm of the operator. Three different power hand held tools a Jigsaw, a Planer and a Random orbital sander were used for analysing the effects on hand arm. Two measurement tools were used a Fingertip tactile pressure sensor for measuring the forces acting on the hand arm and A Tri-axial accelerometer for measuring the vibration caused by these tools in hand arm. To reduce the effects of the hand held tools on hand arm of the operator different coatings on the handle of hand-held power tools including one handle uncoated will be used and then the measurements of vibration and force obtained from these coated handle is then compared with the uncoated handle.

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CHAPTER 1

Introduction

1.1 Background

A variety of hand held power tools are extensively used in various industries. Prolonged exposure of power tools is one of the foremost reasons for transmission of vibrations from the tools to hands of operator. This makes discomfort to users and leads to early fatigue. When fatigue exists, it may cause different disorders in the operators such as physical, musculoskeletal and physiological.

The adverse effects of the lengthy exposure of the vibration caused by the power hand held tools to hand of the operator have known for extended period of time and these occupational disorders is known as ‘Vibration White Finger’ syndrome. Of all professional domains, the construction industry is rated as the most prone to vibration after that industrial sector. The effects or symptoms due to exposure to hand-arm vibration are categorized as vascular, neurological or musculoskeletal. All vascular symptoms fall under the category of ‘Vibration White Finger’ it is classified by the whitening of the operator’s finger triggered by continuous use of vibrating hand-held machinery. The presence of vascular symptoms in operators using portable or vibrating hand-held machinery can be up to 70% or more, based on the type and time period of the exposure.

Commonly found neurological disorders are tingling in the fingers and numbness. The musculoskeletal injury related with hand arm vibration indicates itself in the way of pain in the upper extremities. Hand arm vibration is also a factor for developing carpal tunnel syndrome. Hand arm vibration can vary mostly with a lot of factors that are distinguished as:

- Model of the tool.
- Condition of the tool.
- Direction and location on a tool.
- Working materials.
- Magnitude of hand force applied.
- Working posture.

The amount of operators exposed to have held tool vibration very high all across the world. In advanced and developed nations like France, Finland. The Percentage varied mostly from 4.9

to 10.9. Most dominated sectors are construction (63%,), Mining and Manufacturing (44%) and fishing and agriculture (38%).

Construction sector use of power hand held vibratory tool is of great importance. Burström et al. (2004) found metal workers in which the tools make low vibration with acceleration between 2.1 and 2.5 m/s^2 but presence of neurological symptoms (47%) and vascular (39%) still exists, and the vascular occurrence rate is alarming as 24.2 cases in 1000 exposure in a year. Hand tools not only affect nerves and vascular structure of the hands but they also affect the bone structure.

For these issues, it is necessary to have information about the response of hand system with respect to the vibration exposure. The biodynamic response of the finger is very different from the palm (Dong et al., 2005). As the vibration is most likely to have more association with health effects due to induced vibration, therefore it is very important to classify and to understand these vibration transmission.

The relationship between the disorders and the vibration characteristics such as frequency, direction and magnitude is not known yet, but it is agreed that starting of these disorders can be decreased by decreasing the magnitude of transmitted vibration on the hand. Konz et al., (1990) and Mital and Kilborn, (1992b) proposed that the surface of the handle should be smooth and should have little compressibility. The logic for this recommendation is that it distributes surface pressure evenly, it is easy to grip and also it decreases the vibration when compared with incompressible materials.

Working in different postures also varies the magnitude of the hand arm vibration transmitted by the power hand held tools (Joshi et al., 2012). Therefore to reduce the disorders associated with these hand transmitted vibration, it’s very important to enhance the design of handle to decrease the vibration transmission.

Decreasing the vibration transmission magnitude from the power tool towards the hand of the operator is been identified as a very effective method to reduce the hand arm vibration syndrome (Morioka, 2009; Mallick, 2010).

There are mainly two simple approaches for reducing the hand arm vibration from the hand power tools. First is of the use gloves and the second is to use of the coating on the tools handles by which the vibrations are generally transmitted to the operator’s hands.

It has been found that the extensive use of gloves can have both positive as well as negative influences on the hand movement. Plummer et al., (1985) found that use of gloves decreases the hand movement and efficiency of the operator. Sudhakar et al., (1988) reported that the use of gloves also have negative effect on the grip forces as compared with the no gloves condition. These vibration energy transmission and absorption by the operator’s hand results in deformation of the tissues.

There is a lot of variation in the influence of the gloves on the vibration transmission Goel and Rim (1987) found that while operating pneumatic chipping hammer, that use of padded, leather padded glove decrease the magnitude of hand arm vibration when compared with no glove condition but Gurram et al., (1994) indicated the use of gloves doesn’t have any effective decrease in the vibration by the power hand held tools.

The commercial found antivibration gloves have no effect on vibration below 100 Hz they only attenuate high frequency vibrations. There is also a case in which there is variation in vibration reduction at different parts of the hand arm (Dong et al., 2010a,b) this indicates that the influence of the gloves is location oriented.

There is another approach which is using coating of the damping materials on the handle of the tools which can also be used for decreasing the magnitude of the vibration that is transmitted at hand to the hand held tools.

Most of the issues related with gloves could also be prevented by using this approach. But the costs of the materials that are useful for damping the vibration are very costly.

In nations like India, the suppliers are not eager to use of these costly tools. Thus it is very difficult in developing and under developed nations to find ways which are cheaper to decrease the problems associated with the hand arm vibrations.

Therefore it is necessary to use coatings that are generally relatively of low cost so that it can be useful in these countries.

In this study different coating materials are that is use on the different tools handle and the effect of these of the hand arm vibration in the hand is investigated.

1.2 Hand-arm vibration syndrome

Exposure to the vibration in the hand arm system is a very recent occupation hazard in the industrial sectors. While the vibration on the hand arm of the operator have been in since the starting of the use of the power hand held tools, concern over the damages caused by the HAVS (Hand arm vibration syndrome) has been lagging behind the from similar occupational hazards such as chemical hazards and noise. As the safety engineers all over the world are collectively working on the installation of both an Exposure limit value and an Exposure action value to the noise standards.

The disorders comprising of the HAVS (Hand arm vibration syndrome) has been stated as extensively and more often as vascular, neurological and musculoskeletal (Heaver et al. 2011). A distinguish system the Stockholm Workshop Scale (SWS), is generally used for the stage of the most of the sign and symptoms, for the neurological and vascular contents separately (Brammer et al. 1987; Gemne et al. 1987). This scale was developed in the era of 1980s (Brammer et al. 1987; Gemne et al. 1987), and even after criticism (Griffin 2008), this is still one of the most frequently applied system for the classification and assessment of the severances of symptoms. Classification is generally based on the history and the physical examination only, and it involves very few of the symptoms that are present in HAVS. It has been founded (Griffin 2008) that the "scope and form of every signs and the symptoms which are caused by the hand-transmitted vibration are relatively not known".

1.3 Objective

The aim of this research work is to find out the vibration and forces generated by the power hand held tools and the effect of these on the hand arm of the operator by using three different power hand held tools a Jigsaw, a Planner and a Random orbital sander and to reduce these effects on hand arm of operator by using different coating over the handle of the tool.

1.4 Motivation

Prolonged, intensive exposure to forces and vibrations generated by powered hand tools may cause hand–arm vibration syndrome. Vascular symptoms in workers using portable or hand-held vibratory tools can be as high as 70% or more, depending on the type and duration of exposure. There are mainly two ways for reducing the vibrations transmitted from the hand held power tools to the operator's hand. First is to use anti-vibration gloves and other one is the use of coating over the handles by which the vibrations are transmitted to the hands. In nation like India the contractors are not ready for the use these expensive tools. Therefore the task is very difficult in the developing and the underdeveloped countries to find out cheaper ways for reducing problems because of the hand vibrations transmission. Therefore it is very important to made coatings that are comparatively cheap so that they can be used in countries for overcoming the workers problems. In this study three coatings are used in the handle and their effect on the transmission of vibration at the hand will be investigated.

CHAPTER 2

Literature Survey

2.1 Overview

A lot of work is done in the field of the hand arm vibration system. The major work done on the field of hand arm vibration is given in the Table 2.1. Then the work is categorized in the work done in the field of the anti-vibration gloves in the Table 2.2. The vibration power absorption is categorized in the Table 2.3 which gives the various experiments done on the field of the power absorption in the hand arm system of the operator.

2.2 Major works done so far on hand arm vibration

Table 2.1 Major works done so far on hand arm vibration

Sl. No.	Title	Author	Source	Remark
1.	Evaluating worker vibration exposures using self-reported and direct observation estimates of exposure duration	Margaret McCallig, Gurmail Paddan , Eric Van Lentea, Ken Moore, Marie Cogginsa	Applied Ergonomics Volume 42, Issue 1, December 2010, Pages 37–45	They compared the objective and the subjective method for Hand arm vibration over an 8 hour working day and found that the self reported time estimate from the survey was 9 times greater compared with direct observation. Using the questionnaire exposure times were 66% greater during observed exposure time.
2.	Hand-transmitted vibration in power tools: Accomplishment of standards and users' perception	Margarita Vergara, Joaquin-Luis Sancho, Pablo Rodriguez, Antonio Perez-Gonzalez	International Journal of Industrial Ergonomics 38 (2008) 652–660	The values that were measured in study of hand transmitted vibration in power tools show that there can be important differences in the levels of vibration generated by the same kind of tools, which suggests that vibration can be reduced by studying the way they are designed.
3.	The vibration transmissibility and driving-	Xueyan S. Xu, , Daniel E. Welcome, Thomas	International Journal of Industrial Ergonomics Volume 41, Issue 5,	They observed that the distributed response of the hand is usually varied with each finger's location, frequency of vibration and the force applied by hand. Two major

	point biodynamic response of the hand exposed to vibration normal to the palm	W. McDowell, John Z. Wu, Bryan Wimer, Christopher Warren, Ren G. Dong	September 2011, Pages 418–427	resonances are observed in the vibration transmission. In first the transmission is less. The second is observed on the finger as the frequency varies mostly among the finger and specific location of finger, it is difficult to find this resonance in the biodynamic response driving point
4.	Short communication Effects of hand vibration on reflex behaviors and pain Perception- A pilot study	Hee-Sok Park!, Bernard Martin"	International Journal of Industrial Ergonomics 23 (1999) 629-632	They investigated the effects of the hand vibration over the protective reflex response of the stimulus intensity. The responses were stronger when the vibration was strong and were more visible in the lower frequency vibration. A poor correlation during vibration was discovered between the reflex response and the stimulus perception.
5.	Comparative analysis of exposure limit values of vibrating hand-held tools	Mónica López-Alonso Rosalía Pacheco-Torres Ma Dolores Martínez-Aires Javier Ordoñez-García ,	International Journal of Industrial Ergonomics 43 (2013) 218e224	They analyzed the exposure amount of the vibration to the construction workers. In this research vibration magnitude of the general tools were compared and they recorded the maximum time that a tool can be used safely. In the result they observed that 42 % of the tools cross the daily exposure limit.
6.	Ergonomic analysis of fastening vibration based on ISO Standard 5349 (2001)	Akul Joshi Ming Leu Susan Murray	Applied Ergonomics 43 (2012) 1051-1057	They examined two hand held power tools which are used for the fastening operation with the operators having different postures. The two tools were a right angled nut runner and the second was offset pistol grip, they observed that pistil grip tool makes more vibration when compared the right angles nut runner on the hand working at different postures.
7.	Experiment	Ignacio	International	They performed experiment on the

	-al evaluation in uncertainty in the hand arm vibration measurements	Ainsa, David Gonzalez, Miguel Lizaranzu, Carlos Bernad	Journal of Industrial Ergonomics 41 (2011) 167-179	handles of they are of real machines while it is used by operator. They observed that methods used for fixing and the behavior of accelerometer is the two main reason of the uncertainty. The uncertainty found is up to 8 % of the value

2.3 Major work done so far on anti-vibration gloves

Table 2.2 Major work done so far on anti-vibration gloves

Sl. No.	Title	Author	Source	Remark
1.	The effects of vibration-reducing gloves on finger vibration	Daniel E. Welcome, Ren G. Dong, Xueyan S. Xu, Christopher Warren, Thomas W. McDowell	International Journal of Industrial Ergonomics Volume 44, Issue 1, January 2014, Pages 45–59	While working on the vibration reducing (VR) gloves Daniel E. Welcome et al. 2013 found that the effect of these gloves on the finger vibration depend not only the gloves but also their influence on the distribution of the finger contact stiffness and the grip effort. The gloves enhance the vibration in the fingertip area but reduce the vibration in the proximal area at frequencies below 100 Hz. On average, the gloves reduce the vibration of the entire fingers by less than 3% at frequencies below 80 Hz but increase at frequencies from 80 to 400 Hz. At higher frequencies, the gel-filled glove is more effective at reducing the finger vibration than the air bladder-filled glove.
2.	Analysis of anti-vibration gloves mechanism and	Ren G. Dong, Thomas W. McDowell, Daniel E.	Journal of Sound and Vibration Volume 321, Issues 1–2, 20 March 2009, Pages	Ren G. Dong et al. 2008, analyzed the anti vibration gloves mechanism and their evaluation methods. They developed a model based on the driving point mechanical impedances which are

	evaluation methods	Welcome, Christopher, Warren, John Z. Wua, Subhash Rakheja	435–453	present in the palm and finger of the hand without the glove. They proposed a new biodynamic approach for the evaluation of the overall effectiveness of the anti vibration gloves for the hand this new approach doesn’t require the interface of the on the hand measuring device, that not only interfere with the gripping of the handle but also disturbs the dynamic properties of the hand.
3.	Tool-specific performance of vibration-reducing gloves for attenuating palm-transmitted vibrations in three orthogonal directions	Ren G. Donga, Daniel E. Welcomea, Donald R. Peterson, Xueyan S. Xua, Thomas W. McDowell, Christopher Warrena, Takafumi Asaki, Simon Kudernatsch, Antony Brammer	International Journal of Industrial Ergonomics Volume 44, Issue 6, November 2014, Pages 827–839	They studied the VR gloves and find out the effectiveness of the gloves. Estimated tool-specific performance of the vibration reducing gloves for reduction in the vibration magnitude in three direction 3-D. they estimated that the gloves can slightly reduce (<5%) or amplify (<10%) the vibration which are generated from low frequency tools, they can reduce the palm transmitted vibration in the range of 5-8 % depending on the specific tool used.

4.	Effectiveness of a new method (TEAT) to assess vibration transmissibility of gloves	R.G. Dong, ,S. Rakheja, W.P. Smutz, A. Schopper, D. Welcome, J.Z. Wu	International Journal of Industrial Ergonomics Volume 30, Issue 1, July 2002, Pages 33–48	This method (TEAT) is used in the study for the vibration isolation; They analyzed the measured data symmetrically. The degree of the misalignment of the adapter varied from 5.9 to 59.6 degree. This variation can cause large errors in the estimation of about 20 %. They concluded that the method is based on the vector sum of the source and the acceleration response can yield large reputability and effective assessment of the gloves used.
5.	Estimation of tool-specific isolation performance of Anti-vibration gloves	S. Rakheja, R. Dong, D Welcome, A.W. Schopper	International Journal of Industrial Ergonomics 30 (2002) 71–87	They developed a methodology to estimate the effectiveness of anti-vibration gloves. Six different tools are used and two different gloves. They recorded that the frequency response of the gloves are comparatively insensitive to the value of the vibration but largely depends on the visco elastic behavior of the anti-vibration glove materials.
6.	Correlation between biodynamic characteristics of human hand–arm system and the isolation effectiveness of anti-vibration gloves	R.G. Dong, T.W. McDowell, D.E. Welcome, W.P. Smutz	International Journal of Industrial Ergonomics 35 (2005) 205–216	They studied the major factors which are generally associated with the effectiveness of the gloves. In first they measured the apparent mass of hand arm system and in second they measured the transmissibility of Anti vibration glove by using a palm adapter. They found that glove becomes more effective when the apparent mass was increased. They also found that the stiffness is the key factor that influence the biodynamic response of the glove transmissibility when measure in the palm of the operator.

2.4 Major works done so far on vibration power absorption

Table 2.3 Major works done so far on vibration power absorption

Sl. No.	Title	Author	Source	Remark
1.	Distributed vibration power absorption of the human hand-arm system in different postures coupled with vibrating handle and power tools	S. Adewusi ,S.Rakheja P.Marcott M.Thomas	International Journal of Industrial Ergonomics Volume 43, Issue 4, July 2013, Pages 363–374	S.A. Adewusi et al. 2009 found that the vibration transmissibility, tend to decrease with increasing distance between the measurement location and the source also suggested that operators of power tools with frequencies below 25 Hz may experience greater muscles/tissues fatigue and symptoms of musculoskeletal disorder when working with extended arm posture.
2.	A method for analyzing absorbed power distribution in the hand and arm substructures when operating vibrating tools	Jennie H. Dong, Ren G. Dong, Subhash Rakheja, Daniel E. Welcome, Thomas W. McDowell, John Z. Wu	Journal of Sound and Vibration 311 (2008) 1286–1304	Jennie H. Dong et al. 2007, studied different methods for analyzing the distribution of power in the hand arm of the operator when the operators are working on the vibratory tools. They made a five degree freedom model of which can take measurement of the finger as well as the palm of the operators, different grip force positions were used. They found that the standardized weighting, may overestimate effects due to low frequency of vibration but it greatly underestimates the effects of the high frequency vibration on the fingers of the operators.
3.	Tuned vibration absorber for suppression of hand-arm	Ko Ying Hao, Lee Xin Mei, Zaidi Mohd Ripin	International Journal of Industrial Ergonomics Volume 41, Issue 5,	They used a tuned vibration absorber in the electric grass trimmer and recorded that minimum vibration was on the shaft the trimmer. The TVA has the best performance of reduction of 95

	vibration in electric grass trimmer		September 2011, Pages 494–508	% of vibration on the position of accelerator. The average reduction in Z axis was of 84 % and 72 % in X axis for the operation of cutting, For no cutting operation the lessening of vibration is of 82 % in Z axis and 67 % in X axis .
4.	A method for analyzing vibration power absorption density in Human fingertip	John Z.Wu , RenG.Dong,Daniel E. Welcome, Xueyan S. Xu	Journal of Sound and Vibration 329 (2010) 5600–5614	In this study they predicted that the VPAD (Vibration power absorption density) is a good factor for determining the vibration exposure in the fingers of the operator. They found that the VPAD was good for finger surface transmissibility at the frequency which is greater than the first resonance, which suggests that it can be used as an alternate for assessing the exposure.
5.	Frequency weighting derived from power absorption of fingers–hand–arm system under zh-axis vibration	Ren G. Dong, Daniel E. Welcome, Thomas W. McDowell, John Z. Wu, Aaron W. Schopper	Journal of Biomechanics 39 (2006) 2311–2324	The main objective of his experiment is to derive frequency weighing from three VPA methods which are hand VPA, Palm VPA, finger VPA. They observed that the total power absorption of the hand arm system is to mostly correlate with the discomfort or subjective sensation. Hand and palm methods are less likely to predict any better relation if the ISO method can't predict better result.
6.	Influence of hand forces and handle size on power absorption of the human hand–arm exposed to zh-axis vibration	Y. Aldien, P.Marcotte S.Rakheja, P.-E´ Boileau	Journal of Sound and Vibration 290 (2006) 1015–1039	They studied the effect of the size of handle and the force on the hand with three cylindrical handles in different postures. They found that absorbed power was to be better related with coupling force when compared with the contact force when the power is in low frequency range. Power absorbed is mainly dependent on the size of the handle. It is directly proportional the size of the handle.

2.5 Summary

In the literature review all the ways of reducing the vibration is considered and after reviewing them all of the methods have some negative effects mostly on the hand movement of the operator. Thus to overcome this negative effect coating of the tools is selected as it not only reduces the vibration transmission but also is helpful in comfort and hand movement of the operator.

CHAPTER 3

Tools and Measuring Instruments

3.1 Overview

To perform the experiment different tools and measuring instruments are used. Mainly for measuring the vibration a tri-axial accelerometer is used, for measuring the force on the finger tip of the operator a force finger tip sensor is used and for hand held tools three main tools are Jigsaw, Sander and Planer. In this chapter the detailed specification and the working of these tools are given.

3.2 Tri-axial accelerometer

The vibration transmitted to the hand–arm system was measured using a tri-axial accelerometer, and the signal was recorded with a VibroMetra vibration meter Figure 3.1 which directly gives the vector sum of vibration of all three axis in m/s^2

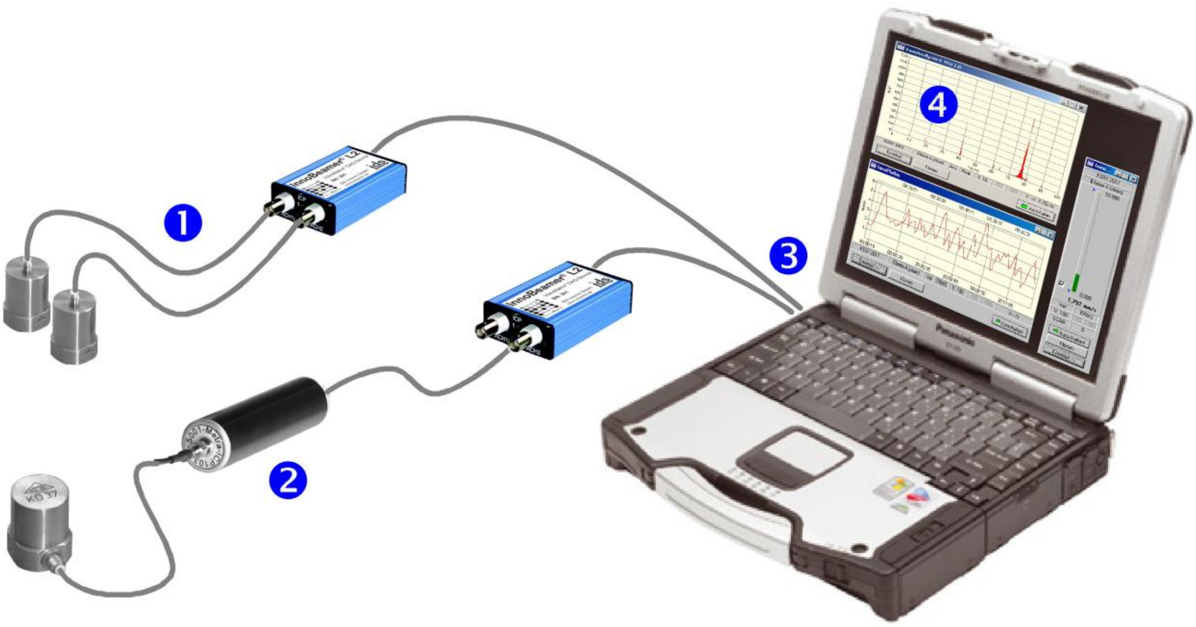


Figure 3.1 Vibration Measurement system

1. Piezoelectric sensors with integrated amplifier are directly connected to the PC via the M302 or M312 USB adapter.

2. Piezoelectric sensors with charge output to transmit their signals to the PC as well.

3. One or more M302 or M312 units are connected to the USB interface of the PC. The PC supplies the M302 or M312 with energy. No external power supply is required.

4. The software instruments have been tailored for various measuring applications. Still, all instruments can work on the PC screen at the same time. You can combine them at will. The operation is performed by mouse. The results are displayed in real-time, high resolution and colour.

3.3 Finger tip force sensor

The finger force sensor is a pressure tactile sensor which is having five finger sensor and a palm sensor for measuring the force in the finger tip and palm of the operator. It is connected with a hand connector Figure 3.2 which is worn in the wrist of the operator having six element connector for transmitting the force signal Figure 3.3 to the computer.

Figure 3.2 Finger tip sensor with the sensor connector

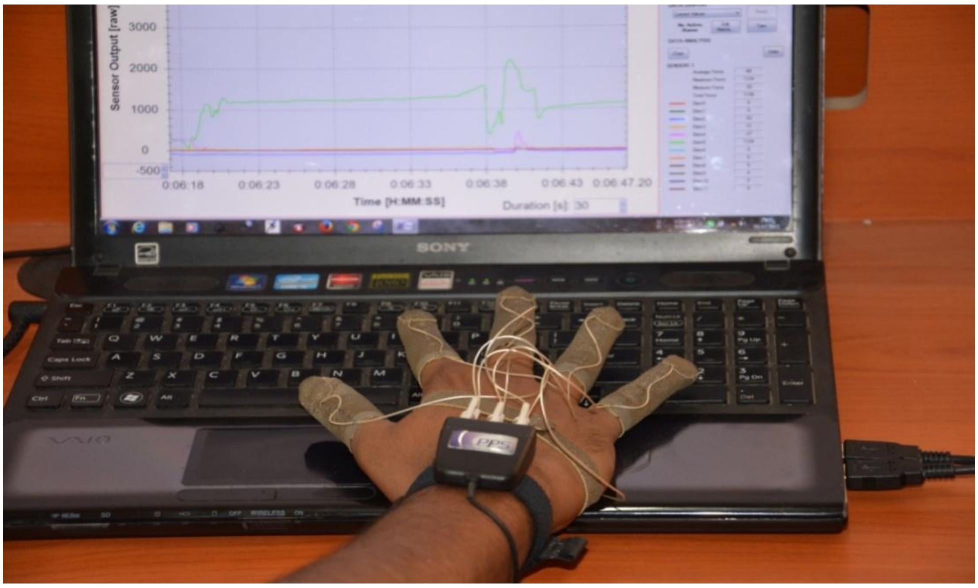


Figure 3.3 Finger tip sensor connected with laptop

3.4 Hand held tools

Three hand held tools are used in the experiment that is Jigsaw, Planer and random orbital sander, they are used in softwood for performing the operations. In Table 3.1 the specific task and the material used for the operation is specified. The tools used are given in the Figure 3.4.

Table 3.1 Tool, Operation performed, Material

Tool	**Operation**	**Material**
Jigsaw	Cutting	Softwood
Planer	Flatness, reducing thickness	Softwood
Random orbital Sander	Sanding	Softwood

3.4 (a)

3.4 (b)

3.4 (c)

Figure 3.4 Tools used in experiment (a) Jigsaw (b) Orbital Sander (c) Planer

3.5 Summary

Detail description and the operation to be performed by the tools are explained. The specification and the parts used in the material are briefly described.

CHAPTER 4

Methodology

4.1 Overview

To perform the experiment the detail procedure and the methods which are used in this experiment is described in this chapter. The no participants and their anthropometric data is given in the tabular form in the table 4.1 and the procedure for finding the magnitude of vibration and force is described.

4.2 Approach

When working with the hand held power tools there is a considerable amount of transmission of the vibration form the tools to the hand of the operator. The vibration can have severe effects on the hand arm system of the operators causing fatigue and disorders in the hand arm of the operators thus making it very difficult to work on the tools and have a lifelong negative effect to the operator. Thus to reduce these hand arm vibration from the tools to the operators it can be reduced by use of the anti-vibration gloves or by using the coating of damping materials on the surface of the handles of the hand tools. Anti vibration gloves have a lot of negative effects on the working of the operators while using hand tools.

Use of gloves reduces the efficiency and also the hand movements of the operator. As the efficiency of the operator is reduced these is a considerable amount of increase in the working time of the operator which results in the slow production in the industries. Thus to overcome the problem which are associated the use of anti vibration gloves coating of some readily and cheaply available damping materials is used. Coating of handles has a lot of positives when compared with the anti vibration gloves most of the negatives associated in the gloves can be overcome by use of the coating.

The advantages of using the coating are that it can be used as integrated part of the tools when compared with the gloves. In this experiment the reduction of the vibration is done by the use of coating of damping material on the handles of the hand held tools with some very readily and cheaply available damping materials which are most commonly available in the market. Thus the coating of damping material is preferred when compared the anti vibration gloves which are costly and have many negative effect on the operators body.

4.3 Participants

Ten male participants (Right handed) participated in this experiment. Their anthropometric data is recorded and are listed Table 4.1. All of the ten participants used were in healthy condition with all of them having no history of vascular of neurological problem. The participants given their interest for willingly participation in the experiment and have no problem while performing the operations. Their approval was taken before the commencement of the experiment.

Table 4.1 Anthropometric data of the subjects

Participant	**Hand Length(mm)**	**Hand Breadth(mm)**
1	183.5	83.6
2	186.7	84.9
3	189.8	82.6
4	190.2	83.9
5	188.6	85.5
6	185.6	84.6
7	187.9	84.2
8	185.4	85.3
9	185.7	84.3
10	184.9	86.7
Mean	**186.83**	**84.56**

4.4 Coating Material

The handle of the power hand held tools used in this experiment which are Jigsaw, Planer and Random orbital Sander are coated with three different type of coating of damping materials Table 4.2. They were coated in such a way that they can be removed when the operator doesn’t require performing the experiment and can be fitted in any of the three hand tools handle. While performing the experiment one reading was taken for all hand tools without the coating material for comparing with the coated hand tools for finding out the vibration transmission. The most important properties which are considered in the selection of the coating material were basically vibration reduction, the amount of comfort of material while holding the power tools, durability of the coating materials, low cost, and availability of the materials.

Table 4.2 Type of coating and coating materials used for reduction of vibration

S. No	Coating Name	Coating Materials
1	C1	Uncoated
2	C2	Sponge
3	C3	Rubber Sheet
4	C4	Cotton

These coating materials are coated for such a way that the diameter of the handle of the tools should be comfortable with gripping the hand tools also there is not much difference in the uncoated and coated handle of the hand tools. These coating materials provide better grip as well as good comfort while working when compared with bare or uncoated hand held tools. Basically all of the three material used are useful in damping the vibration and can be used by the operators while working on the tools.

4.5 Procedure

Three hand held power tools Jigsaw, Planer and an Orbital Sander are used in the experiment to calculate the vibration and forces. Ten male subjects (Right handed) volunteered in participation in the experiment. Two instruments are used in the experiment a force Sensor for measuring the forces in the finger tip and palm and a Tri-axis accelerometer for measuring the vibration.

The participants are asked to perform each operation of cutting from Jigsaw, Reducing thickness from Planer and sanding operation form Orbital Sander on Softwood and Plywood for 70 seconds. Vibrations and Forces is measured for 60 seconds for each case. Vibrations are measured at the wrist of using a tri-axial accelerometer and the forces are measured in finger and the palm of the participants using force Sensor.

The Vibration data recorded is then compared with the ISO defined daily exposure action value. Isolation of vibration is done by using different coating materials. Comparison is made between the coated and the uncoated tools for and transmissibility ratio is recorded for giving the effectiveness of the coating of damping materials. Similarly these coatings will be used for the force reduction the coated and uncoated tool's force is measured and then they are compared with each other for calculating the percentage reduction of force in the tools.

4.6 Summary

The produce for performing the vibration and force test on the hand held tools are described. The participants used in this experiment and their anthropometric data are recorded. The coatings used for the reduction in the vibration transmissibility are given in Table 4.2. The three different coating and their materials are explained.

CHAPTER 5

Vibration and Force Measurement

5.1 Overview

The measurement of vibration and force by the tri-axial accelerometer and finger tip sensor in the wrist of the operators is explained in this chapter. The positioning of the accelerometer and the finger tactile sensor is given in this chapter. The interface of the finger tip sensor with the laptop is explained in this chapter.

5.2 Vibration Measurement

The measurement of the vibration were performed our in the accordance of the ISO 5349-1 (2001) (HAV). Measurement was made by using a Tri-axial accelerometer for measuring out the amount of the vibration in the hand tools. It can give out the value of vibration for every 1-s interval in the unit of m/s^2 also a force sensor also know as fingertip sensor is used for measuring the force on the finger tip of the hand of the operator. The force sensor measures the force on the finger as well as the palm of the operator. The tri-axial accelerometer is calibrated automatically after every subject while performing the experiment for each tool. Similarly the force sensor is provided with a calibration plate for calibrating the finger tip as well as palm sensor. The forces sensor is also calibrated after every subject while performing the operations with the tools.

For measuring out the vibration on the tools handle the accelerometer was tightly attached to the handle of the to the hand held tools using a plastic strip which was already provided by the manufacturer for clamping of the accelerometer over the hand of operator. Intense care was taken to make sure that there is no interference in the working of the subjects while performing on the hand tools during the experiment. The average, maximum and minimum vibration of the tools was calculated while using the root mean square (r.m.s) weighted acceleration measured in the unit of m/s^2 (ISO 5349-1, 2001). In Figure 5.1 the position of the tri-axial accelerometer is given. The interface with the laptop is done by the two usb adapters which are provided by the manufacturer.

Figure 5.1 Position of the tri-axial accelerometer on the wrist of the operator

The tri-axial accelerometer was connected with the computer with help of the usb cables having two cables for two usb adapters which then is connected with the usb port of the computer used for displaying the results of the measurement of the vibration and also for the recording the magnitude of the vibration. The tri-axial accelerometer is configured according to the ISO 5349 (2001). Two usb adapters Figure 5.2 are used for measuring the vibration in all the tree axis i.e. x, y and z axis.

Figure 5.2 Two USB adapters with the USB cable for connecting with the computer

The ISO standards basically define four ways of fixing the accelerometer. These are gluing, use of Hose-clip connections, use of hand adapters for fixing the accelerometer and in last screwing. The weight of the adapter should not be high as these the weights effects the measurement of the vibration of the hand tools (Gurram et al., 1994). NIOSH (1989) recommends that the weight of the tri-axial accelerometer should be less than of the 5g and the whole weight of accelerometer with the use of hand adapter should not increase the limit of 20g so as to reduce the error in the measurement of the vibration and also to increase the accuracy of the measurement.

5.3 Force Measurement

The force sensor which is a finger tactile pressure sensor is worn on the finger and palm of the operator. These sensors were connected with the help of sensor connector to the hand adapter which is worn on the wrist of the operator. The hand adapter is connected with the computer with the help of usb Bluetooth adapter for receiving the signal. The hand adapter is rechargeable by the use to usb to mini usb cable. The operation duration the adapter is around 3-4 hours

The size of the finger tip sensor Figure 5.3 used is normal size which can be easily worn on the operators. The finger tip sensor consists of thumb, index, middle, ring, pinky and palm. The software can be used for calibrating Figure 5.4 as well as the measurement of the average, maximum and minimum force working on the operator’s finger and palm.

Figure 5.3 Finger Tip sensors with hand adapter worn on the wrist.

Figure 5.4 Calibration plate for the calibration of the Finger Tip sensor

When selecting upon a time period to represent the whole operation, care was taken for ensuring that the sample period which is selected should also represent the whole work cycle. In all the cases of the three hand held tools used the operation performed is repetitive in nature.

For all the hand held tools used in this experiment two 60 s hand vibration measurement were made for every tool and subject, small measurement period of about 5 s have been selected for the high degree of repeatability in between measurement of vibration (Paddan et al., 1999).

5.4 Summary

The measurement of the force and vibration is explained and the positioning of the finger tip sensor and accelerometer on the wrist of the operator is given in Figure 5.1 for tri-axial accelerometer and Figure 5.3 for finger tip force sensor.

CHAPTER 6

Result and Discussion

6.1 Overview

The vibrations on the wrist of the operator performing the operation were recorded. The reading of the uncoated tool is taken first thus to find out how much magnitude of vibration is being produced by not using any coating of damping materials and it is then also used for comparing result of the coated tools for finding out the vibration reduction and the transmissibility ratio between the coated and the uncoated tool. Lesser the transmissibility ration there is greater chance of reduction in the magnitude of the vibration. The reading were recorded in the vector sum of the entire three axis x, y, z axis.

6.2 Vibration level of uncoated tool

Value of the uncoated tool for the vibration and force are summarized in tables given below giving out the maximum, minimum and mean vibration value and the average force value of all the ten subjects participated in the experiments.

Table 6.1 Mean, Minimum and Maximum Vibration of Jigsaw

Subject	Mean (m/s)	Minimum	Maximum
1	1.82	0.72	2.55
2	1.79	0.85	2.67
3	1.77	0.77	2.50
4	1.96	0.83	2.66
5	1.90	0.87	2.69
6	1.89	0.79	2.53
7	1.92	0.75	2.67
8	1.87	0.82	2.63
9	1.75	0.87	2.68
10	1.83	0.79	2.64

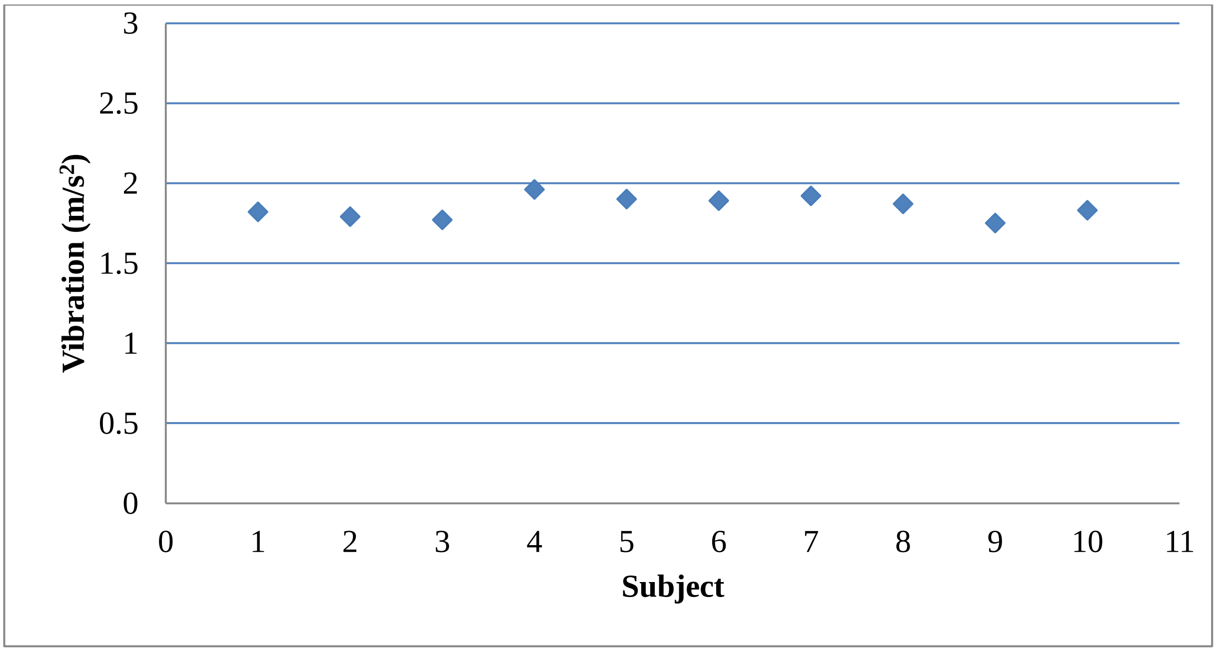


Figure 6.1 Scatter graph of mean vibration reading of Jigsaw

Table 6.2 Mean, Maximum and Minimum Vibration Reading of Orbital Sander

Subject	**Mean(m/s^2)**	**Minimum(m/s^2)**	**Maximum(m/s^2)**
1	1.21	0.45	2.75
2	1.08	0.66	2.64
3	1.32	0.49	2.73
4	1.12	0.55	2.45
5	0.97	0.46	2.47
6	1.20	0.52	2.61
7	1.13	0.60	2.73
8	1.17	0.67	2.80
9	1.23	0.59	2.82
10	1.10	0.61	2.86

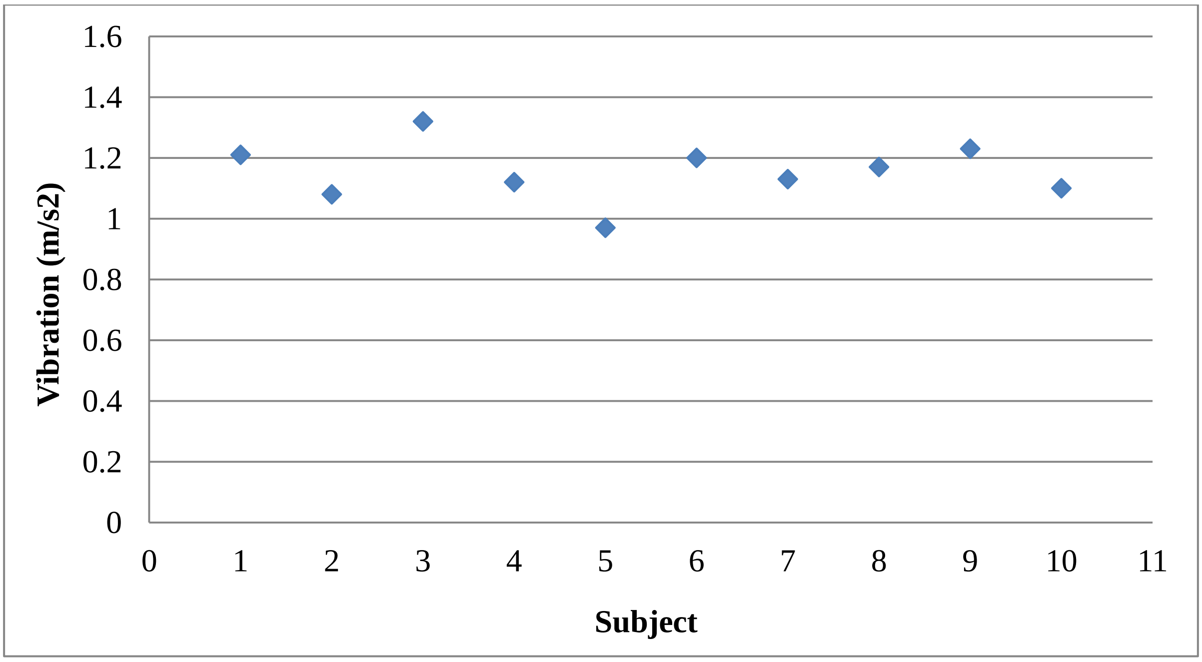


Figure 6.2 Scatter graph of mean vibration reading of Orbital Sander

Table 6.3 Mean, Maximum and Minimum Vibration Reading of Planer

Subject	Mean(m/s^2)	Minimum(m/s^2)	Maximum(m/s^2)
1	2.12	1.07	3.27
2	2.35	1.12	3.13
3	2.17	1.09	3.20
4	2.19	1.17	3.25
5	2.25	1.16	3.19
6	2.33	1.19	3.22
7	2.28	1.14	3.26
8	2.33	1.13	3.22
9	2.28	1.17	3.17
10	2.27	1.08	3.24

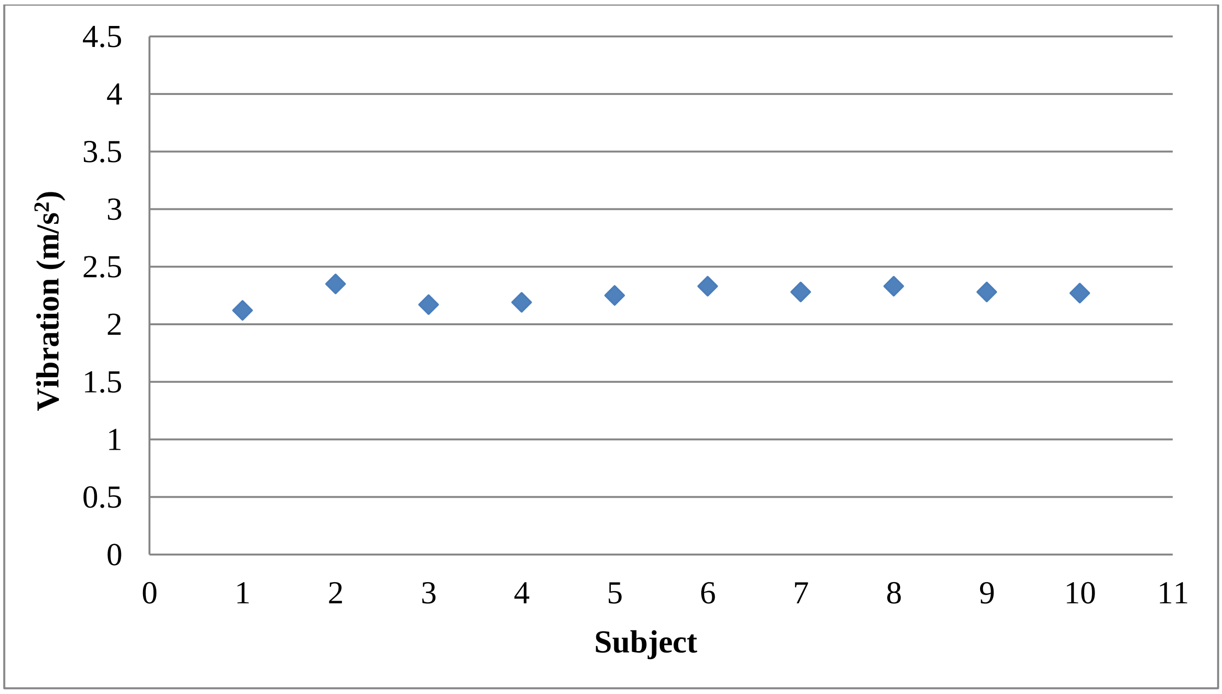


Figure 6.3 Scatter graph of mean vibration reading of Planer

Values for the vibration of Jigsaw is given in the Table 6.1 the scatter graph for the vibration is in Figure 6.1, for the values of Orbital sander are given in the Table 6.2 and the scatter graph is given in the Figure 6.2 and for Planer the recorded vibration value in the give Table 6.3 and the scatter graph is plotted between the vibration magnitude an participants in Figure 6.3. It is found out that all of these tools are having vibration greater than that of the limit defined by the European directive 2002/44/EC where the exposure action value (EAV) =2.5 m/s^2. Therefore there is a need of coating the handles of the tools for reducing the vibration produced.

6.3 Vibration level of coated tools

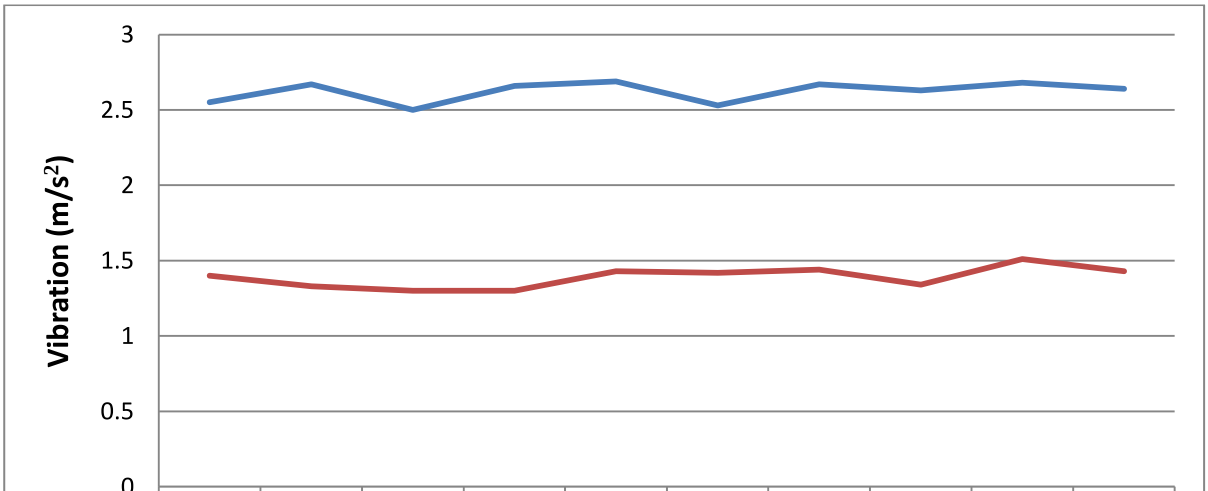
The uncoated tool is named as C1 and the three coated tools are name as C2, C3 and C4 for all three hands held tools which are Jigsaw, Orbital Sander and Planer. The reading for both the coated and uncoated tools is measured and compared in the tables given below also the transmissibility ratio is calculated for measuring out the amount of reduction in the vibration level of the tools. The less the transmission of vibration from the tool to the hand of the operator the less will be the transmissibility ratio of that coated tool. Equation 6.1 gives the transmissibility ratio as ratio of vibration of coated and uncoated handle of tool.

$$\text{Transmissibility Ratio} = \frac{\text{Vibration of the coated handle}}{\text{Vibration of the uncoated handle}} \tag{6.1}$$

6.4 **Vibration level for Jigsaw**

Table 6.4 Comparison of Uncoated (C1) and Coated tool (C2) Jigsaw

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C2)	Transmissibility Ratio
1	2.55	1.40	0.55
2	2.67	1.33	0.50
3	2.50	1.30	0.52
4	2.66	1.30	0.49
5	2.69	1.43	0.53
6	2.53	1.42	0.56
7	2.67	1.44	0.54
8	2.63	1.34	0.51
9	2.68	1.51	0.56
10	2.64	1.43	0.54



	1	2	3	4	5	6	7	8	9	10
C1	2.55	2.67	2.5	2.66	2.69	2.53	2.67	2.63	2.68	2.64
C2	1.4	1.33	1.3	1.3	1.43	1.42	1.44	1.34	1.51	1.43

Figure 6.4 Comparison of C1 (Uncoated) and C2 (Coated) Jigsaw Tool

Table 6.5 Comparison of Uncoated (C1) and Coated tool (C3) Jigsaw

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C3)	Transmissibility Ratio
1	2.55	1.12	0.47
2	2.67	1.15	0.43
3	2.50	1.05	0.42
4	2.66	1.20	0.45
5	2.69	1.13	0.42
6	2.53	1.09	0.43
7	2.67	1.10	0.41
8	2.63	1.16	0.44
9	2.68	1.23	0.46
10	2.64	1.16	0.44

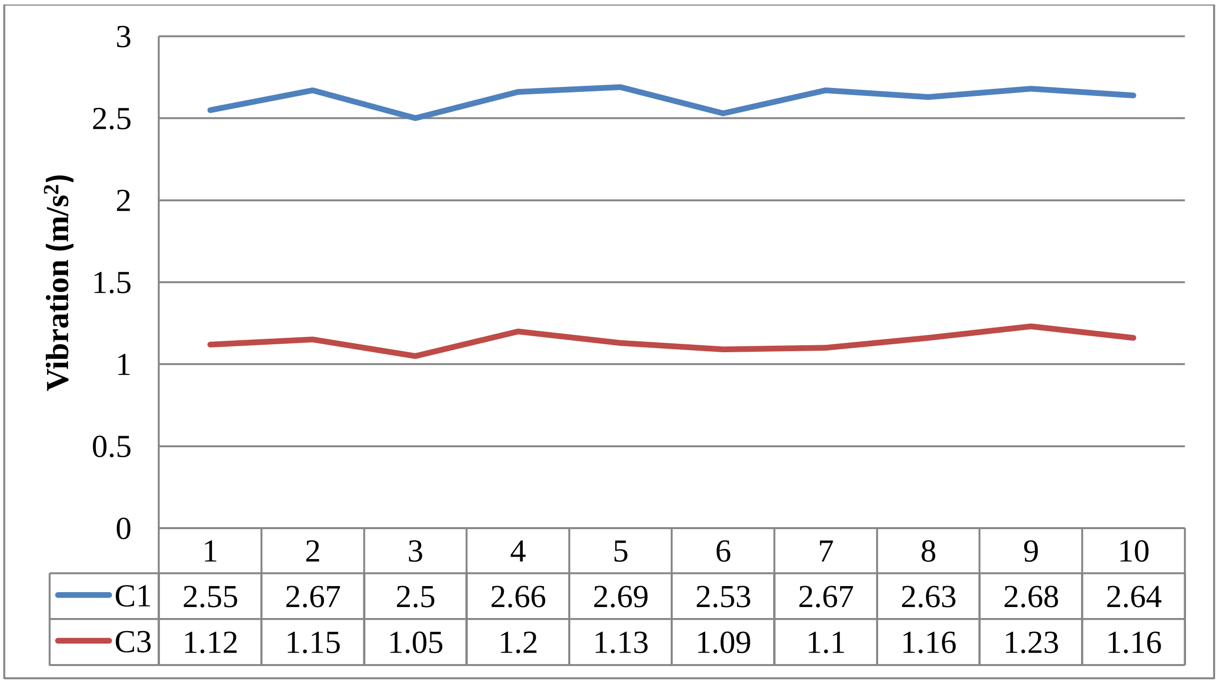


Figure 6.5 Comparison of C1 (Uncoated) and C3 (Coated) Jigsaw Tool

Table 6.6 Comparison of Uncoated (C1) and Coated tool (C4) Jigsaw

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C4)	Transmissibility Ratio
1	2.55	1.25	0.49
2	2.67	1.20	0.45
3	2.50	1.15	0.46
4	2.66	1.28	0.48
5	2.69	1.37	0.51
6	2.53	1.27	0.50
7	2.67	1.17	0.44
8	2.63	1.21	0.46
9	2.68	1.29	0.48
10	2.64	1.24	0.47

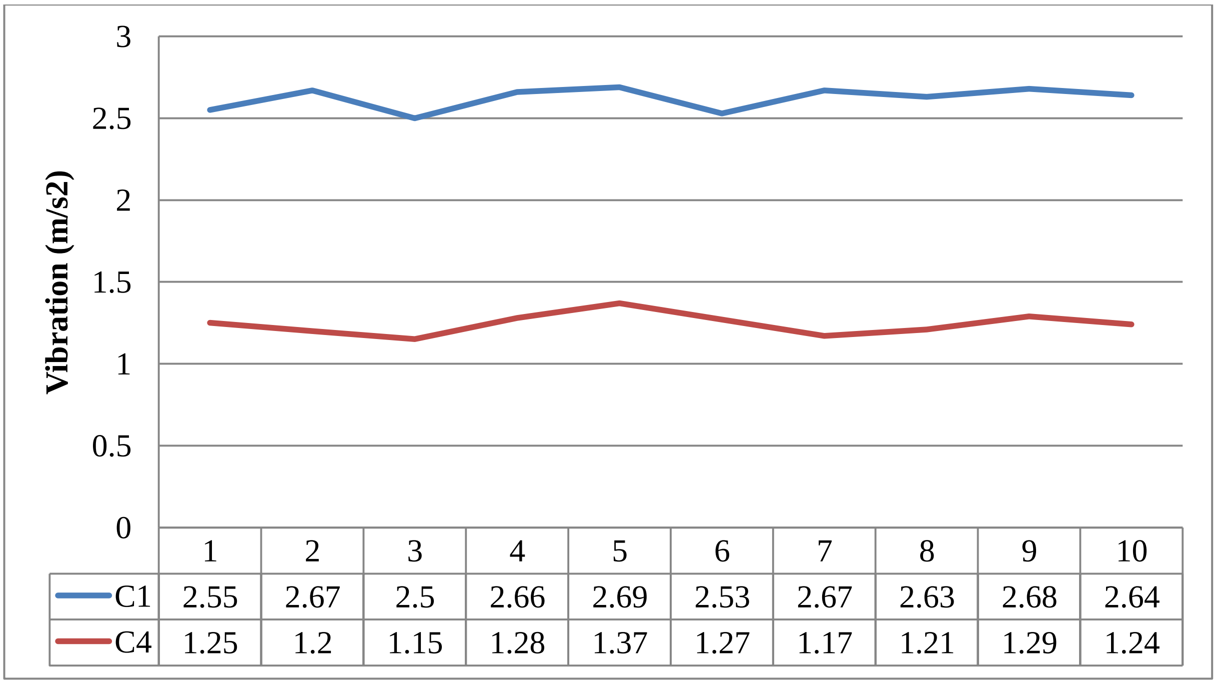


Figure 6.6 Comparison of C1 (Uncoated) and C4 (Coated) Jigsaw Tool

6.5 Vibration level for Orbital sander

Table 6.7 Comparison of Uncoated (C1) and Coated tool (C2) Orbital Sander

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C2)	Transmissibility Ratio
1	2.75	1.54	0.56
2	2.64	1.43	0.54
3	2.73	1.56	0.57
4	2.45	1.32	0.54
5	2.47	1.21	0.52
6	2.61	1.33	0.51
7	2.73	1.50	0.55
8	2.80	1.37	0.49
9	2.82	1.35	0.48
10	2.86	1.49	0.52

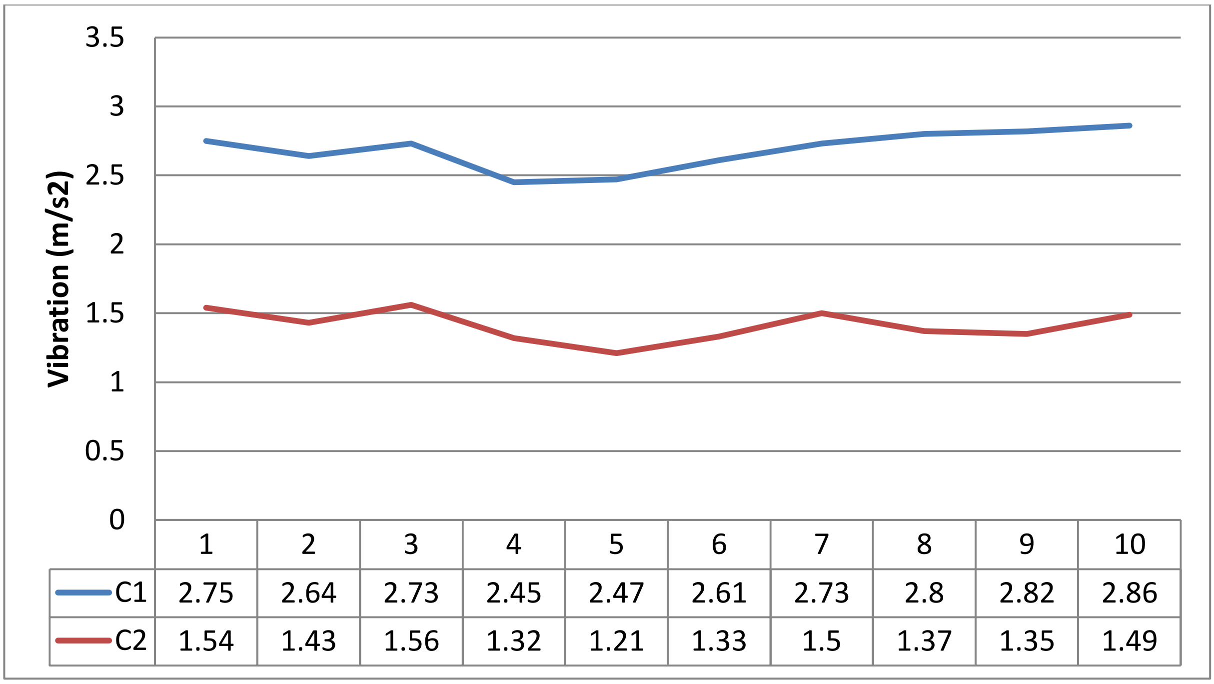


Figure 6.7 Comparison of Uncoated (C1) and Coated tool (C2) Orbital Sander

Table 6.8 Comparison of Uncoated (C1) and Coated tool (C3) Orbital Sander

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C3)	Transmissibility Ratio
1	2.75	1.18	0.43
2	2.64	1.24	0.47
3	2.73	1.23	0.45
4	2.45	1.13	0.46
5	2.47	1.01	0.41
6	2.61	1.23	0.47
7	2.73	1.23	0.45
8	2.80	1.15	0.41
9	2.82	1.22	0.43
10	2.86	1.26	0.44

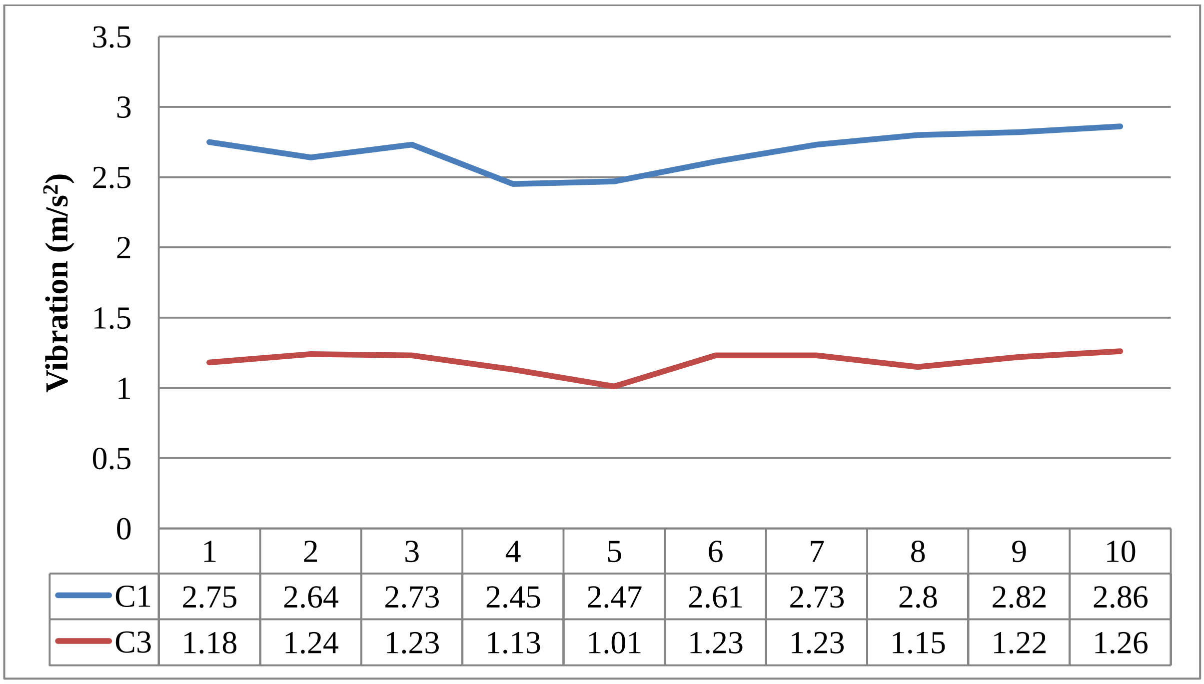


Figure 6.8 Comparison of Uncoated (C1) and Coated tool (C3) Orbital Sander

Table 6.9 Comparison of Uncoated (C1) and Coated tool (C4) Orbital Sander

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C4)	Transmissibility Ratio
1	2.75	1.32	0.48
2	2.64	1.30	0.49
3	2.73	1.39	0.51
4	2.45	1.08	0.44
5	2.47	1.16	0.47
6	2.61	1.20	0.46
7	2.73	1.37	0.50
8	2.80	1.37	0.49
9	2.82	1.44	0.51
10	2.86	1.34	0.47

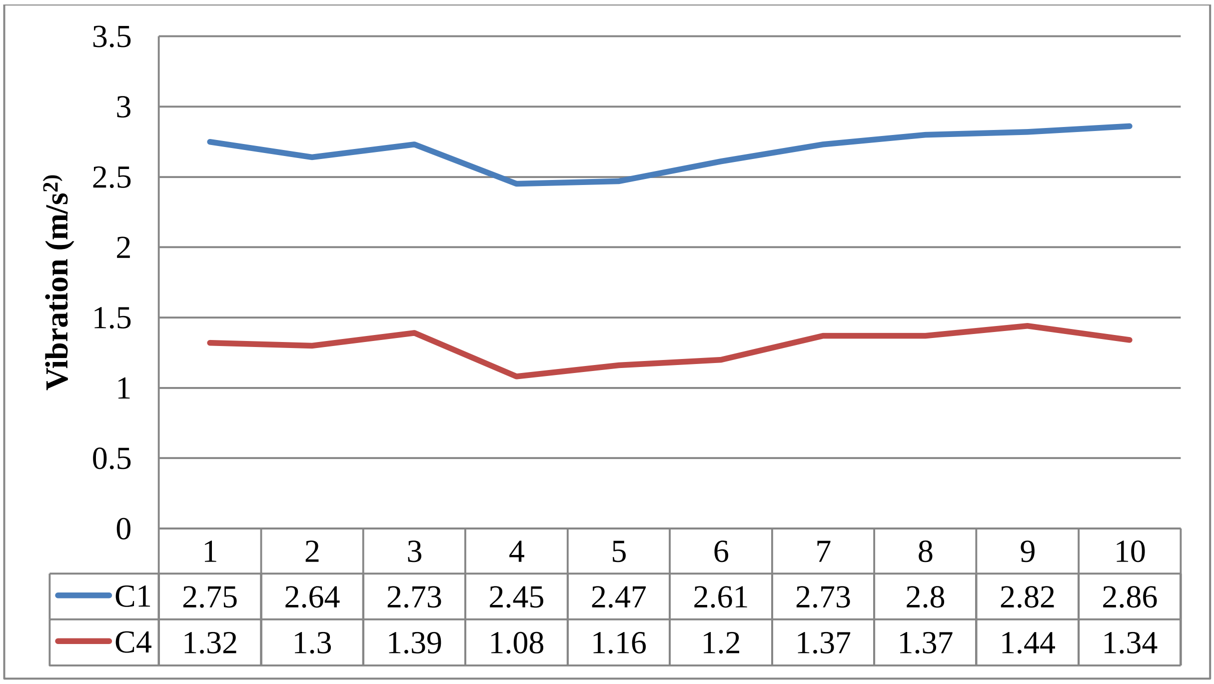


Figure 6.9 Comparison of Uncoated (C1) and Coated tool (C4) Orbital Sander

6.6 Vibration level for Planer

Table 6.10 Comparison of Uncoated (C1) and Coated tool (C2) Planer

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C2)	Transmissibility Ratio
1	3.27	1.71	0.52
2	3.13	1.78	0.57
3	3.20	1.86	0.58
4	3.25	1.66	0.51
5	3.19	1.56	0.49
6	3.22	1.71	0.53
7	3.26	1.76	0.54
8	3.22	1.64	0.51
9	3.17	1.65	0.52
10	3.24	1.59	0.49

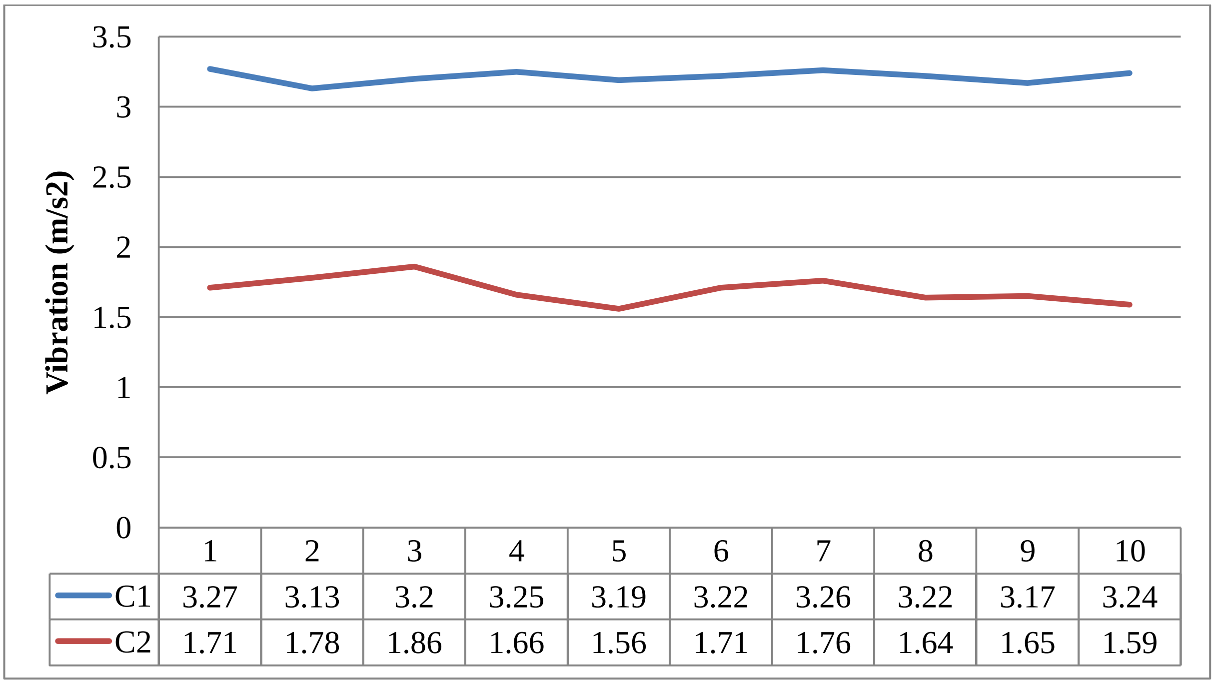


Figure 6.10 Comparison of Uncoated (C1) and Coated tool (C2) Planer

Table 6.11 Comparison of Uncoated (C1) and Coated tool (C3) Planer

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C3)	Transmissibility Ratio
1	3.27	1.57	0.45
2	3.13	1.44	0.46
3	3.20	1.38	0.43
4	3.25	1.43	0.44
5	3.19	1.50	0.47
6	3.22	1.42	0.44
7	3.26	1.40	0.43
8	3.22	1.48	0.46
9	3.17	1.33	0.42
10	3.24	1.46	0.45

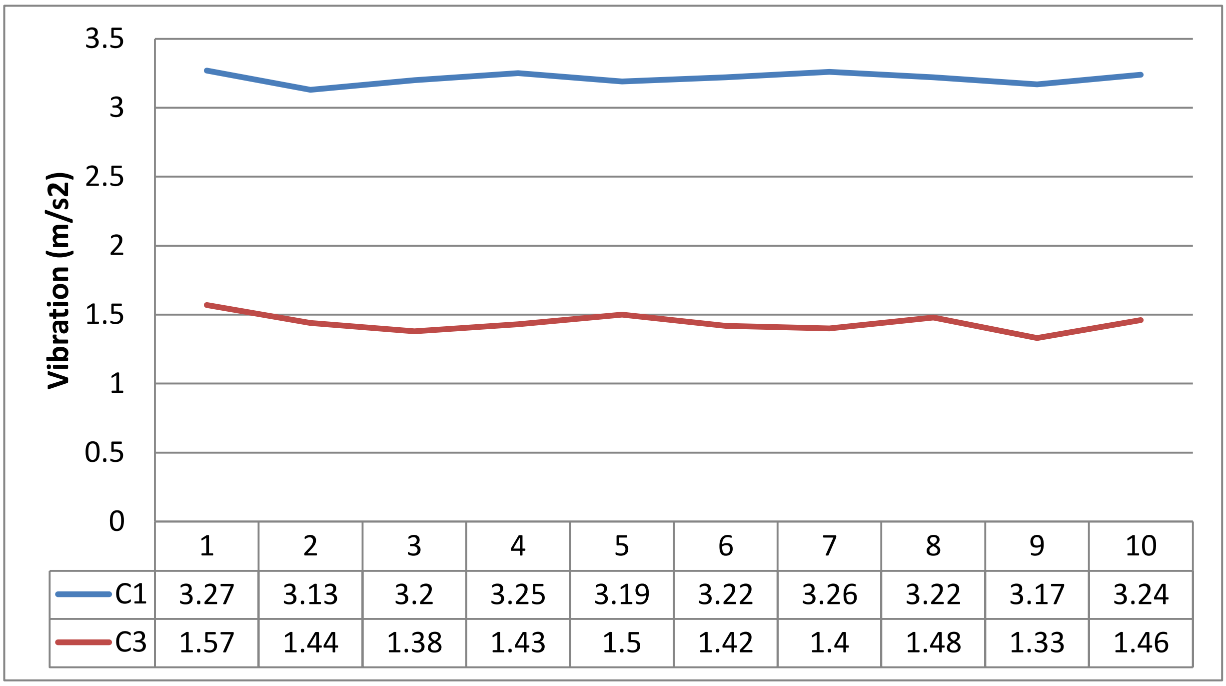
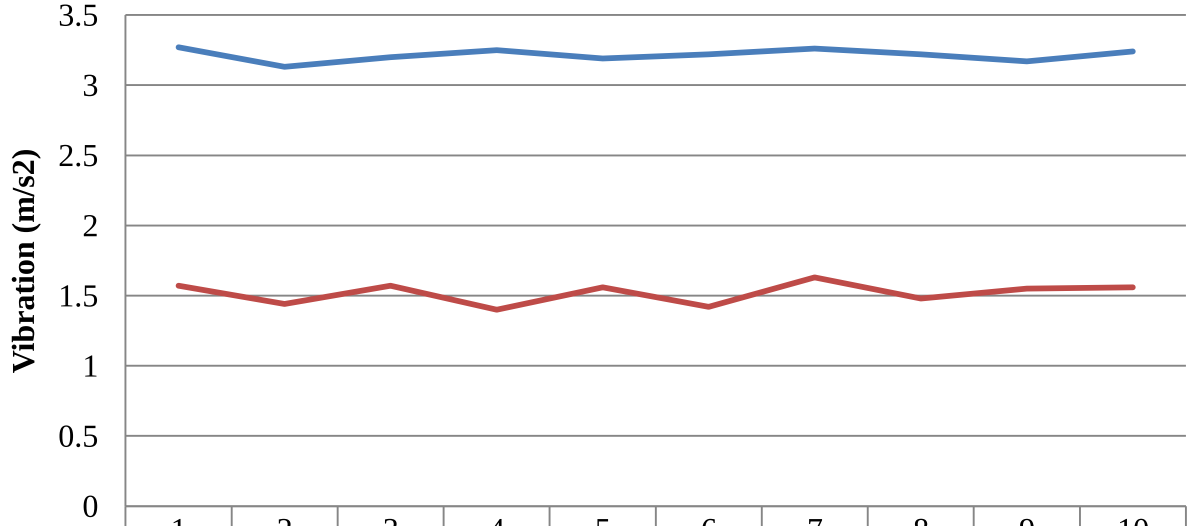


Figure 6.11 Comparison of Uncoated (C1) and Coated tool (C3) Planer

Table 6.12 Comparison of Uncoated (C1) and Coated tool (C4) Planer

Subject	Uncoated (m/s^2) (C1)	Coated (m/s^2) (C4)	Transmissibility Ratio
1	3.27	1.57	0.48
2	3.13	1.44	0.46
3	3.20	1.57	0.49
4	3.25	1.40	0.43
5	3.19	1.56	0.49
6	3.22	1.42	0.44
7	3.26	1.63	0.50
8	3.22	1.48	0.46
9	3.17	1.55	0.49
10	3.24	1.56	0.48



	1	2	3	4	5	6	7	8	9	10
C1	3.27	3.13	3.2	3.25	3.19	3.22	3.26	3.22	3.17	3.24
C4	1.57	1.44	1.57	1.4	1.56	1.42	1.63	1.48	1.55	1.56

Figure 6.12 Comparison of Uncoated (C1) and Coated tool (C4) Planer

Table 6.13 Comparison of Average Uncoated and Coated Vibration level for Jigsaw

Coating	Average Maximum Vibration (Uncoated) (m/s^2)	Average Maximum Vibration (Coated) (m/s^2)	Average Transmissibility Ratio
C1	2.62	-	-
C2	2.62	1.39	0.53
C3	2.62	1.14	0.44
C4	2.62	1.24	0.47

Table 6.14 Comparison of Average Uncoated and Coated Vibration level for Orbital sander

Coating	Average Maximum Vibration (Uncoated) (m/s^2)	Average Maximum Vibration (Coated) (m/s^2)	Average Transmissibility Ratio
C1	2.69	-	-
C2	2.69	1.41	0.52
C3	2.69	1.19	0.44
C4	2.69	1.30	0.48

Table 6.15 Comparison of Average Uncoated and Coated Vibration level for Planer

Coating	Average Maximum Vibration (Uncoated) (m/s^2)	Average Maximum Vibration (Coated) (m/s^2)	Average Transmissibility Ratio
C1	3.22	-	-
C2	3.22	1.70	0.53
C3	3.22	1.44	0.45
C4	3.22	1.52	0.47

Table 6.16 Average transmissibility ratio of the coatings

Coating	Average Transmissibility Ratio
C2	0.53
C3	0.44
C4	0.47

Comparison is made between the uncoated (C1) and coated (C2, C3, C4) hand tools for Jigsaw in Table 6.4, Table 6.5 and Table 6.6 respectively, their variation is described in the form of graph also for C1 and C2 in Figure 6.4 for C1 and C3 in figure 6.5 and for C1 and C4 in Figure 6.6.

For Planer the comparison between the vibration value of C1 and C2 is recorded in Table 6.7 and the line graph is in Figure 6.7 for C1 and C3 in Table 6.8 and line graph in Figuer 6.8 and for C1 and C4 is in Table 6.9 and line graph in Figure 6.9. For the Random orbital sander the comparison is described in Table 6.10, Table 6.11 and table 6.12 for C2, C3, C4 respectively. Also the line graph is represented in Figure 6.10, 6.11, 6.12 for C2, C3, C4 respectively. The magnitude of the vibration is measured at the wrist of the operator for both the coated and uncoated or bare tool. Form the above tables we calculated that the maximum vibration is present in the uncoated tool or bare tool. The average maximum vibration for all three tools is 2.62 m/s^2 in Table 6.13 for Jigsaw 2.69 m/s^2 in Table 6.14 and for Orbital Sander and 3.22 m/s^2 in Table 6.15 for Planer, it is clearly given that these tools are exceeding the vibration exposure limit of 2.5 m/s^2 which is the threshold limit for working.

While working in the coated tools the vibration magnitude is reduced to nearly half, in the Jigsaw the vibration in C2 coating is 1.39 m/s^2, for C3 coating is 1.14 m/s^2 for C4 coating is 1.24 m/s^2 so it is clearly seen that coating C3 is giving out the lowest vibration thus making it the most suitable for working on the Jigsaw hand tool. The transmissibility ration of C2, C3 and C4 coating respectively is calculated as 0.52, 0.44, 0.4 respectively in the Table 6.16 from the transmissibility ratio it is calculated that again coating C3 is having the least transmissibility ratio of all the three coatings.

Similarly for working in the coated tools the vibration magnitude is reduced to nearly half for the Orbital Sander tool the vibration in C2 coating is 1.41 m/s^2, for C3 coating is 1.09 m/s^2 for

C4 coating is 1.30 m/s^2 so it is clearly seen that coating C3 is giving out the lowest vibration thus making it the most suitable for working on the Orbital Sander hand tool. The transmissibility ration of C2, C3 and C4 coating respectively is calculated as 0.52, 0.44, 0.48 respectively from the transmissibility ratio it is calculated that again coating C3 is having the least transmissibility ratio of all the three coatings.

For working on the Planer tool the vibration in C2 coating is 1.70 m/s^2, for C3 coating is 1.44 m/s^2 for C4 coating is 1.52 m/s^2 so it is clearly seen that coating C3 is giving out the lowest vibration thus making it the most suitable for working on the Orbital Sander hand tool. The transmissibility ration of C2, C3 and C4 coating respectively is calculated as 0.53, 0.45, 0.47 respectively from the transmissibility ratio it is calculated that again coating C3 is having the least transmissibility ratio of all the three coatings.

The average transmissibility ratio of all the three coating is calculated and found out to be 0.53 for C2, 0.44 for C3, 0.47 for C4, it shows that all three are nearly reducing the vibration up to the magnitude of 50-65 % thus making them suitable to be used by the operators for working on the tools. C3 coating is giving the least transmissibility ratio making it the most suitable coating to be used in the tools for damping out the vibration in hand held power tools.

6.7 Force level of Jigsaw tool

Table 6.17 Force level for uncoated (C1) and Coated (C2) Jigsaw tool

Force	Uncoated Tool (C1) (N)	Coated Tool (C2) (N)
Right Thumb	1.02	0.75
Right Index	1.42	1.06
Right Middle	4.24	3.18
Right Ring	10.47	7.69
Right Pinky	0.51	0.39
Right Palm	27.51	20.23
Maximum Force	27.51	20.23
Minimum Force	0.51	0.39
Total Force	45.17	33.37

Form the above Table 6.17 we can clearly see that there is considerable amount of force reduction in the tool while using a coating the comparison graph is shown in the next page Figure. To show out the outline of how much percentage force reduction is generally in each finger as well as palm of the operator. It is found that all the three coating have considerable amount of force reduction and can be used accordingly to the comfort ability and the grip strength. The total force of the jigsaw from 45.17 N is reduced to 33.37 N Figure 6.13.

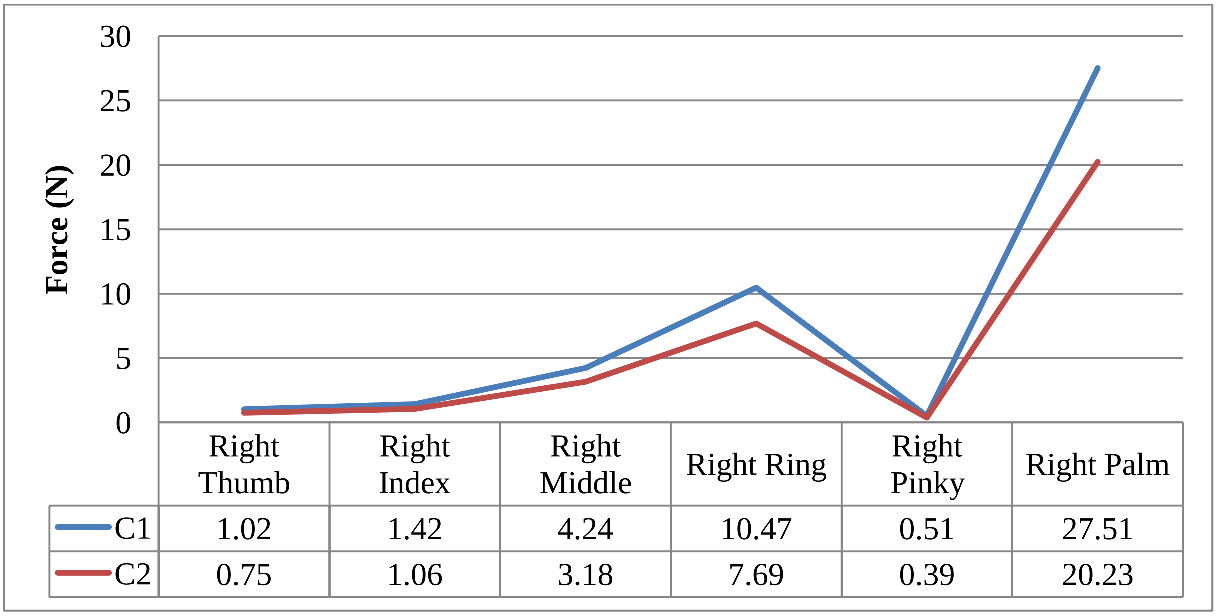


Figure 6.13 Comparison graph between Uncoated (C1) and Coated (C2) Jigsaw Tool

Table 6.18 Force level for uncoated (C1) and Coated (C3) Jigsaw tool

Force	Uncoated Tool (C1) (N)	Coated Tool (C3) (N)
Right Thumb	1.02	0.70
Right Index	1.42	0.97
Right Middle	4.24	2.91
Right Ring	10.47	7.25
Right Pinky	0.51	0.36
Right Palm	27.51	19.10
Maximum Force	27.51	19.10
Minimum Force	0.51	0.36
Total Force	45.17	31.54

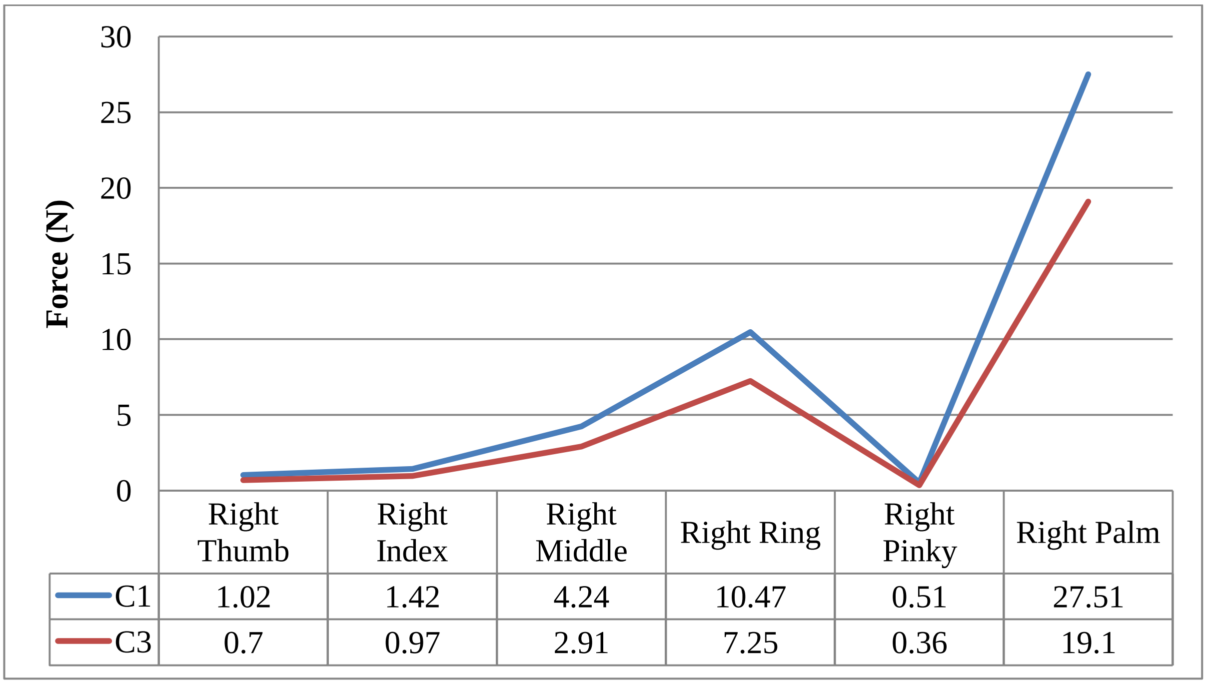


Figure 6.14 Comparison graph between Uncoated (C1) and Coated (C3) Jigsaw tool

Table 6.19 Force level of Uncoated (C1) and Coated (C4) for Jigsaw tool

Force	Uncoated Tool (C1) (N)	Coated Tool (C4) (N)
Right Thumb	1.02	0.73
Right Index	1.42	1.02
Right Middle	4.24	3.05
Right Ring	10.47	7.43
Right Pinky	0.51	0.37
Right Palm	27.51	19.85
Maximum Force	27.51	19.85
Minimum Force	0.51	0.37
Total Force	45.17	32.45

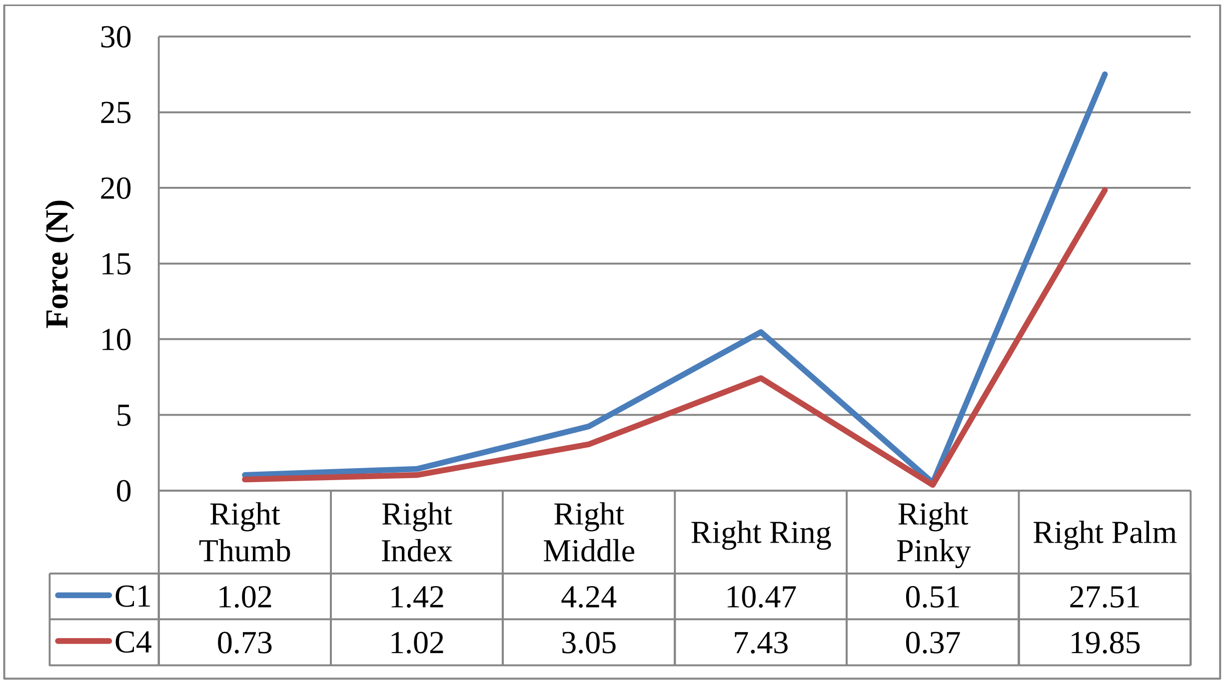


Figure 6.15 Comparison graph between Uncoated (C1) and Coated (C4) Jigsaw tool

6.8 Force level of Planer tool

Table 6.20 Force level of Uncoated (C1) and Coated (C2) for Planer tool

Force	**Uncoated Tool (C1) (N)**	**Coated Tool (C2) (N)**
Right Thumb	3.11	2.30
Right Index	3.40	2.53
Right Middle	7.91	5.81
Right Ring	9.20	6.82
Right Pinky	0.65	0.49
Right Palm	28.32	20.98
Maximum Force	28.32	20.98
Minimum Force	0.65	0.49
Total Force	52.59	38.93

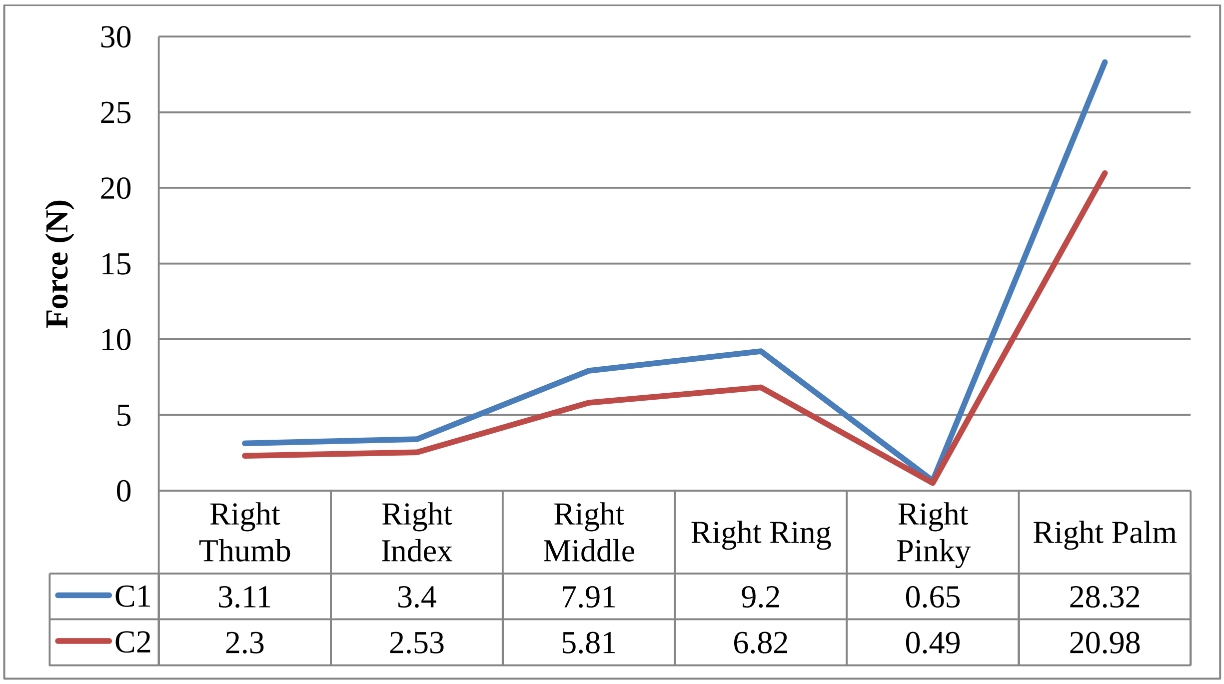


Figure 6.16 Comparison graph between Uncoated (C1) and Coated (C2) Planer tool

Table 6.21 Force level of Uncoated (C1) and Coated (C3) for Planer tool

Force	**Uncoated Tool (C1)**	**Coated Tool (C3)**
Right Thumb	3.11	2.14
Right Index	3.40	2.32
Right Middle	7.91	5.45
Right Ring	9.20	6.35
Right Pinky	0.65	0.45
Right Palm	28.32	19.53
Maximum Force	28.32	19.53
Minimum Force	0.65	0.45
Total Force	52.59	36.24

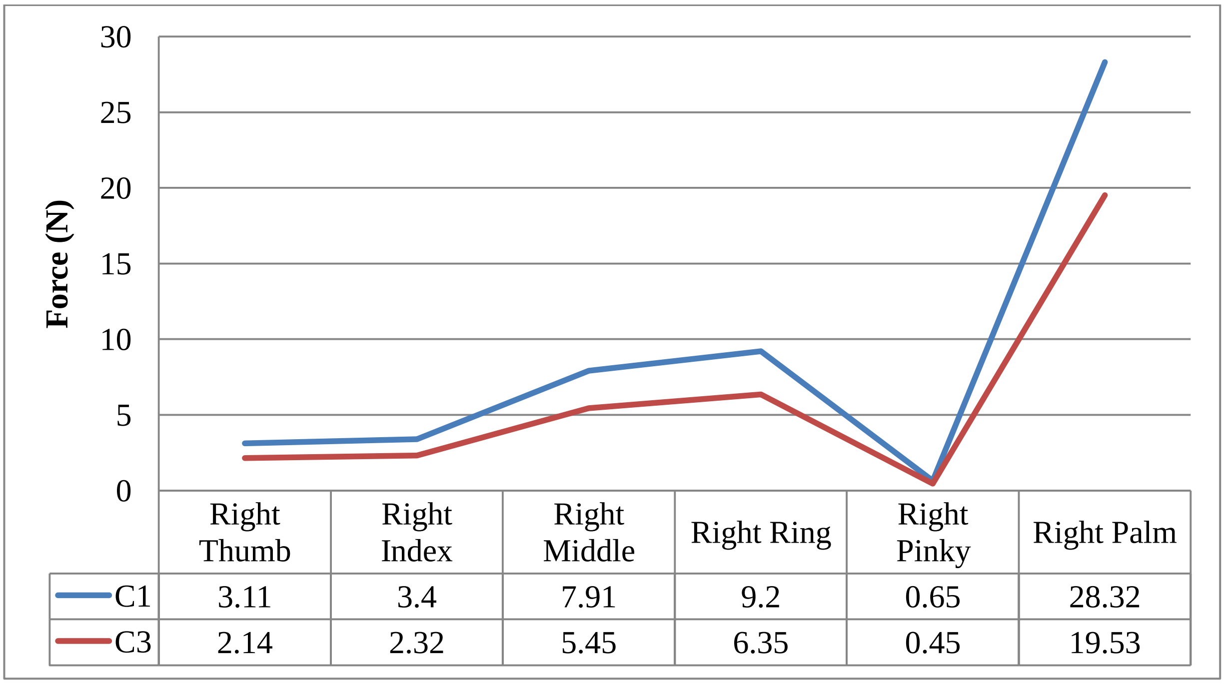


Figure 6.17 Comparison graph between Uncoated (C1) and Coated (C3) Planer tool

Table 6.22 Force level of Uncoated (C1) and Coated (C4) for Planer tool

Force	Uncoated Tool (C1) (N)	Coated Tool (C4) (N)
Right Thumb	3.11	2.23
Right Index	3.40	2.45
Right Middle	7.91	5.60
Right Ring	9.20	6.61
Right Pinky	0.65	0.47
Right Palm	28.32	20.22
Maximum Force	28.32	20.22
Minimum Force	0.65	0.47
Total Force	52.59	37.58

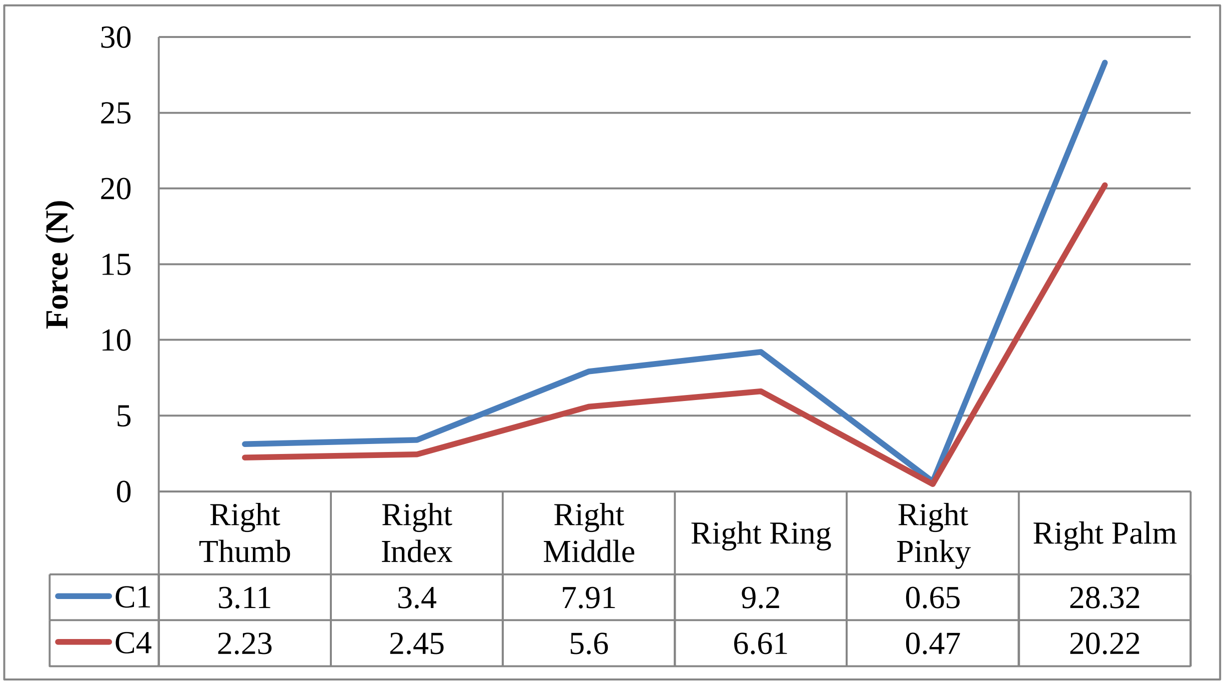


Figure 6.18 Comparison graph between Uncoated (C1) and Coated (C4) Planer tool

6.9 Force level of Orbital Sander tool

Table 6.23 Force level of Uncoated (C1) and Coated (C2) for Orbital Sander tool

Force	Uncoated Tool (C1) (N)	Coated Tool (C2) (N)
Right Thumb	1.44	1.07
Right Index	5.06	3.75
Right Middle	8.03	5.91
Right Ring	12.82	9.57
Right Pinky	0.77	0.56
Right Palm	46.79	34.65
Maximum Force	46.79	34.65
Minimum Force	0.77	0.56
Total Force	74.91	55.51

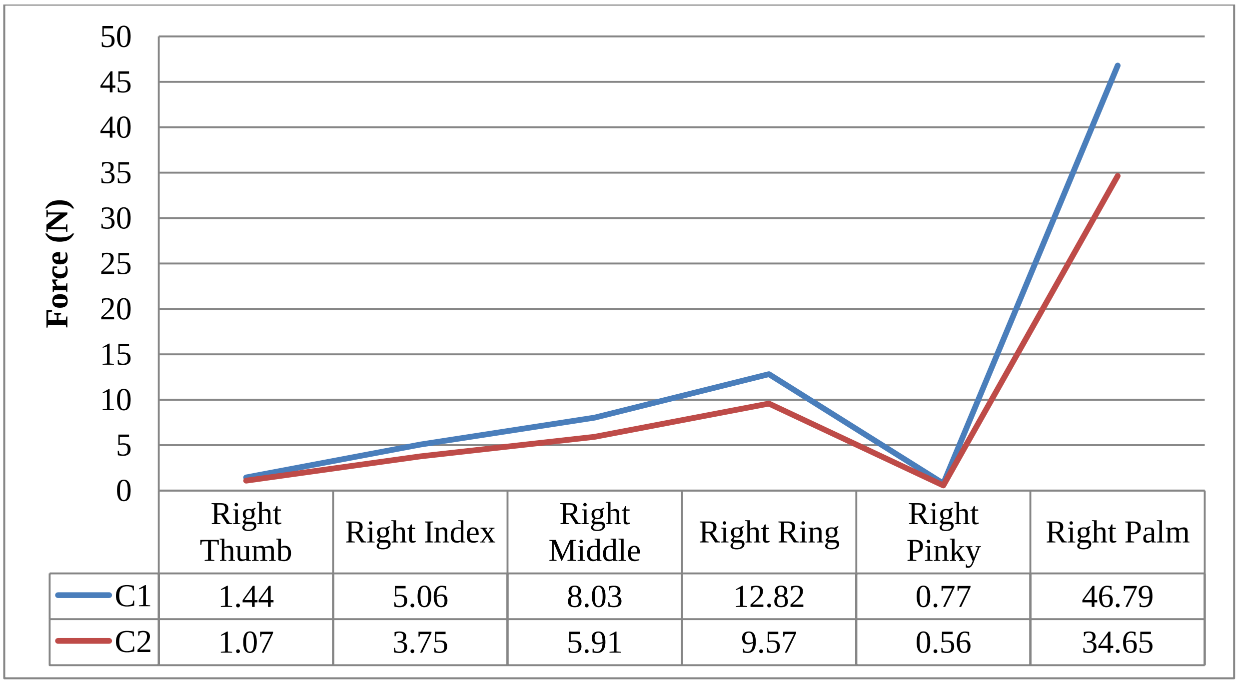


Figure 6.19 Comparison graph between Uncoated (C1) and Coated (C2) Orbital Sander tool

Table 6.24 Force level of Uncoated (C1) and Coated (C3) for Orbital Sander tool

Force	**Uncoated Tool (C1) (N)**	**Coated Tool (C3) (N)**
Right Thumb	1.44	1.01
Right Index	5.06	3.47
Right Middle	8.03	5.50
Right Ring	12.82	8.90
Right Pinky	0.77	0.53
Right Palm	46.79	32.27
Maximum Force	46.79	32.27
Minimum Force	0.77	0.53
Total Force	74.91	51.74

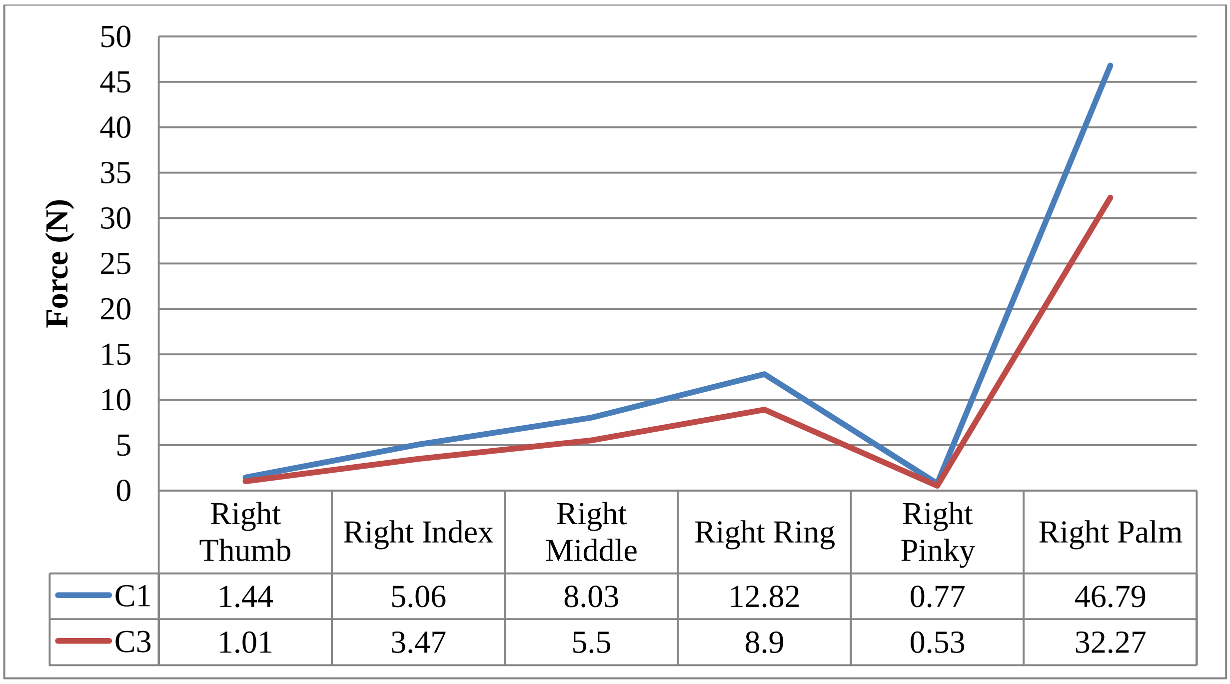
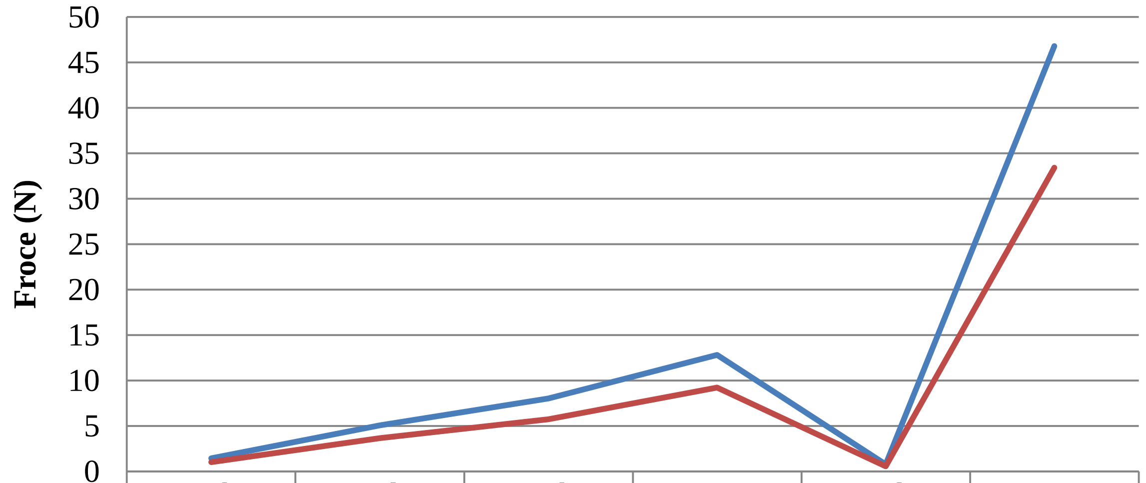


Figure 6.20 Comparison graph between Uncoated (C1) and Coated (C3) Orbital Sander tool

Table 6.25 Force level of Uncoated (C1) and Coated (C4) for Orbital Sander tool

Force	**Uncoated Tool (C1)**	**Coated Tool (C4)**
Right Thumb	1.44	1.02
Right Index	5.06	3.64
Right Middle	8.03	5.73
Right Ring	12.82	9.22
Right Pinky	0.77	0.55
Right Palm	46.79	33.42
Maximum Force	46.79	33.42
Minimum Force	0.77	0.77
Total Force	74.91	53.58



	Right Thumb	Right Index	Right Middle	Right Ring	Right Pinky	Right Palm
C1	1.44	5.06	8.03	12.82	0.77	46.79
C4	1.02	3.64	5.73	9.22	0.55	33.42

Figure 6.21 Comparison graph between Uncoated (C1) and Coated (C4) Orbital Sander tool

In Table 6.17 and Figure 6.13 the Comparison of C1 and C2 coating for jigsaw is given the total force for C1 is 45.17 N and for C2 is 33.37 N. Similarly for C1 and C3 for Jigsaw the total force for C3 is 31.54 N which is given in Table 6.18 and the comparison graph is in Figure 6.14. For C4 coating the total force is 32.45 N given in table 6.19 also the comparison graph is plotted in Figure 6.15.

For planer the total force recorded in C1 is 52.59 N and C2 is 38.93 N in Table 6.20 the graph is given in Figure 6.16. In Table 6.21 the force for C3 is 36.24 N, Figure 6.17 gives the graphical comparison of C1 and C3. 37.58 N is the total force in C4 Table 6.22, graphical comparison is given in Figure 6.18

The total force in Planer is 74.91 N for C1 and 55.51 N for C2 Table 6.23 comparison is made between C and C2 Figure 6.19. For C2 force is 51.74 N Table 6.24, Figure 6.20 gives the comparison of C1 and C3. For C4 total force in C4 is 53.58 N Table 6.25, graphical comparison is in Figure 6.21.

$$\text{Reduction in the Total Force} = \frac{\text{Uncoated Tool Force} - \text{Coated Tool Force}}{\text{Coated Tool Force}} \text{ X } 100\ \% \qquad (6.2)$$

Table 6.26 Total force reduction in the Jigsaw tool

Coating	Total force Uncoated (N)	Total force Coated (N)	Force reduction (In %)
C1	45.17	-	-
C2	45.17	33.37	35.37 %
C3	45.17	31.54	43.21 %
C4	45.17	32.45	39.20 %

The total force working on the Jigsaw is of 45.17 N and total force for Coated Jigsaw tool for Coating C2 is 33.37 N Table 6.26, for Coating C3 is 31.54 N and for coating C4 is 32.45 N. The amount of force reduction is calculated in percentage which is 35.37 %, 43.21 %, 39.20 % for C2, C3, C4 respectively.

Table 6.27 Total force reduction in the Planer tool

Coating	Total force Uncoated (N)	Total force Coated (N)	Force reduction (In %)
C1	52.59	-	-
C2	52.59	38.93	35.09 %
C3	52.59	36.24	45.12 %
C4	52.59	37.58	39.94 %

The total force working on the Planer is of 52.59 N and total force for Coated Planer tool for Coating C2 is 38.93 N from Equation 6.2, for Coating C3 is 36.24 N and for coating C4 is 37.58 N Table 6.27. The amount of force reduction is calculated in percentage which is 35.09 %, 45.12 %, 39.94 % for C2, C3, C4 respectively.

Table 6.28 Total force reduction in the Orbital Sander tool

Coating	**Total force Uncoated (N)**	**Total force Coated (N)**	**Force reduction (In %)**
C1	74.91	-	-
C2	74.91	55.51	34.95 %
C3	74.91	51.74	44.78 %
C4	74.91	53.58	39.81 %

The total force working on the Orbital Sander is of 74.91 N and total force for Coated Orbital Sander tool for Coating C2 is 55.51 N, for Coating C3 is 51.74 N and for coating C4 is 53.58 N Table 6.28. The amount of force reduction is calculated in percentage which is 34.95 %, 44.78 %, 39.81 % for C2, C3, C4 respectively.

6.10 Summary

The value of force and vibration for different coating is recorded and the transmissibility ration for the vibration in coatings when compared with uncoated tool is calculated, also for the force there is considerable amount of force reduction in all the three coating as given in Table 6.28.

CHAPTER 7

Conclusion

7.1 Overview

After recording and calculating the result which are obtained from the tri-axial accelerometer and the finger tip sensor of different tools in different coating conditions the comparison is made between them in this chapter for the most effective in the tools.

7.2 Vibration

Coating of damping materials on the handle of the power hand tool is a very effective method for reducing the vibration which is transmitted to the operator's hand arm system, moreover there is a considerable amount of force reduction in the tools by the use of coating materials.

All the three coatings are able to reduce the force and vibration of the tools and are more comfortable compared to the uncoated handle of the tool. Form the three coating studied, C3 is the most effective coating, it is most effective in absorbing the vibration and force and reduces the transmission of vibration and force to the hand of the operator.

The C3 coating was able to reduce the average maximum vibration magnitude of Jigsaw form 2.62 m/s^2 to 1.14 m/s^2 having the transmissibility ratio 0.44, it is able to reduce the vibration nearly 56 % when compared with the other coatings.

Similarly for the orbital sander the vibration is reduced from 2.69 m/s^2 to 1.19 m/s^2 giving out the transmissibility ratio of 0.44, again the percentage reduction in vibration is 56 %. Also for the Planer the magnitude of the vibration is 3.22 m/s^2 which is reduced to 1.44 m/s^2, the transmissibility ration is of 0.45, which is 55 % reduction in the vibration.

Table 7.1 Average transmissibility ratio

Coating	Average Transmissibility Ratio
C2	0.53
C3	0.44
C4	0.47

The average transmissibility ration for the maximum vibration is 0.53 for coating C2, 0.44 for coating C3 and 0.47 for coating C4 Table 7.1. For C3 0.44 is the least transmissibility ratio which states that it is the most effective of all the coatings and reduces 56 % of the vibration transmission.

7.3 Force

Table 7.2 Average force reduction of different coatings

Coating	Average Force Reduction
C2	35.14 %
C3	44.37 %
C4	39.65 %

Force is also reduced in the coating C3, which gives out the most force reduction when compared with the remaining two coatings. When using for the jigsaw the total force on the hand and palm of the operator is 45.17 N which is reduce to 31.54 N while using the C3 coating.

Similarly for the planer and the random orbital sander the force is 52.59 N and 74.91 N respectively which are reduce to 36.24 N and 51.74 N by the use of C3 coating which is the most force reduction when compared with the other coatings used.

The final average force reduction for coating C2 is 35.14 %, 44.37 for coating C3 and 39.65 % for coating C4 Table 7.2. It is clearly observed that the coating C3 is having the maximum force reduction of the all coating and the most effective to use when compared with the other coatings.

7.4 Summary

From the readings of force and vibration for different tools in different coatings the maximum value of force and vibration is recorded in C1 uncoated tool, the least force and vibration value is in C3. Thus it makes C3 as the most effective in reducing the forces and vibration transmission when compared with the other coatings.

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